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(MANTECH) PROGRAM

ADAPTATION OF PULTRUSION TO THE MANUFACTURE OF HELICOPTER COMPONENTS

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FINAL REPORT

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U.S. ARMY AVIATION RESEARCH AND DEVELOPMENT COMMAND

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The objective of this program was to produce a helicopter component by pultruding a straight preform, then change the contour of that preform during cure without affecting its cross section. Tooling for pultrusion and postforming was designed. Sixteen lower aft cargo door tracks for the Model UH-1 were manufactured.

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PREFACE

This report describes the work accomplished by Bell Helicopter Textron, Inc. (BHTI) under U.S. Army Contract DAAG46-79-C-0089, "Adaptation of Pultrusion to the Manufacture of Helicopter Components".

The program was sponsored by the U.S. Army Aviation Research and Development Command, St. Louis, Missouri, through a contract with the Army Materials and Mechanics Research Center, Watertown, Massachusetts. The contract was administered by Contracting Officers, Mr. Alex Narvaez and Mr. Frank Sousa and conducted under the technical direction of Mr. Noel Tessier. Contracted work began in January 1980 and was completed through process cost analysis in January 1982.

Technical tasks in this program were performed under the technical direction of BHTI Project Engineers, Evan Blake and Robert Anderson. Larry Williams of BHTI Engineering Design was the part designer and Goldsworthy Engineering Inc., Torrance, California, acted as the subcontractor on the pultrusion portion of the program.

Acknowledgement is also given to Reg Tomerlin for his technical assistance, Robert Seago for editing and the laboratory personnel headed by Gerry Peach and Jan Cernosek for their contributions to the project.

This project was accomplished as a part of the U.S. Army Aviation Research and Development Command Manufacturing Methods and Technology (MANTECH) program with the primary objective to develop manufacturing processes, techniques, and equipment for use in the production of Army materiel. Comments are solicited on the potential use of the information presented as applied to present and future programs. Such comments should be sent to:

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St. Louis, Missouri 63166

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SUMMARY

Pultrusion is a process in which a material is pulled through a die producing a shape with a constant cross section. The process is commonly used to produce straight unidirectional fiber reinforced plastic parts. This program sought to develop a process where pultrusions could be formed into curved or contoured shapes adapting them to applications more representative of aircraft components.

A curved UH-1 helicopter door track was selected as the demonstration part. It was pultruded from fiberglass/epoxy prepreg roving and fabric as a straight section. Unidirectional roving was overwrapped wth fabric into a complex cross section that subsequently was formed and cured in the autoclave. The resulting door track retained the cross section of the pultrusion while developing the curve and twist required by the design. Material, wear, and load testing was performed on the composite door track to determine its characteristics and to compare it to the existing aluminum door track. An economic analysis was generated to compare the composite door track with the currently used aluminum track and a hand layedup composite track. A cost analysis of 10, 100, and 1,000 fabricated parts included costs of materials, labor, and tooling.

Sixteen door tracks were successfully fabricated, eight of which were delivered to the Army, demonstrating that it is feasible to produce complex helicopter components utilizing postformed and cured pultrusions.

1. INTRODUCTION

Advances in the performance of reinforced plastics have shown that they can be used in applications long thought to be the exclusive domain of metals. This has developed to the state that almost any structure can be considered using reinforced plastic instead of metal. In the helicopter industry this has progressed to the consideration of the entire airframe as a nonmetallic structure.

These nonmetallic structures can be fabricated by a multitude of processes. The most common method for reinforced plastics has historically been hand layup. Where possible, the industry has incorporated more mechanized processes such as tape laying, filament winding, compression molding, injection molding, extrusion, and thermoforming.

An additional process was developed approximately 35 years ago which produces straight parts with many possibilities of cross sectional design. This pultrusion process is derived from the metal fabrication industry's extrusion process which was developed about 1900 for producing economic constant section metallic parts. Since fiber reinforced plastic resins cannot be pushed through the die by extruding, they are mechanically pulled out of the die, thus the term pultruding. A typical pultrusion operation is shown in Figure 1-1. Most pultrusions are either of fiberglass/polyester or fiberglass/epoxy and are cured in the die. The result is a cross section of almost any degree of complexity as determined by the die, but always straight due to the nature of the die. It has found limited applications in the aerospace field which has a small demand and volume for constant section straight parts.

Therefore the ability to postform a straight pultruded shape into a curved configuration allows pultrusion to be considered for a wider range of applications. This postforming is accomplished before the resin material is cured. The pultrusion machine aligns and shapes the material to the desired form while advancing the state of cure. The pultruded part is not cured, merely in an advanced stage sometimes called the B-stage. In this condition it can be formed while retaining the cross sectional shape and dimensions.

This is the approach taken in this program. The following sections describe the manner in which this was accomplished.

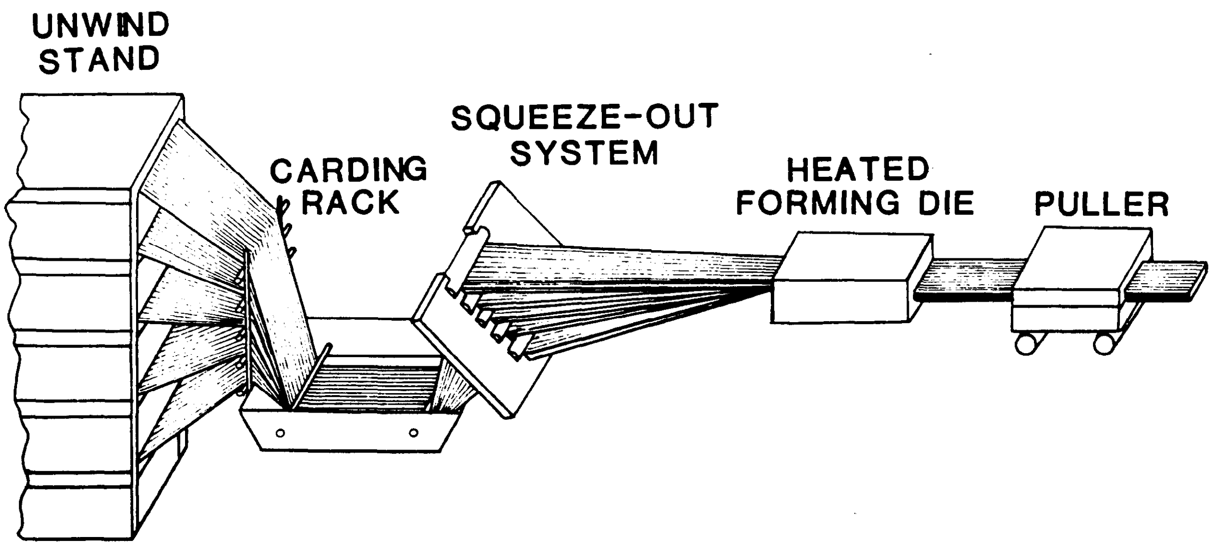


Figure 1-1. Typical pultrusion operation.

2. BACKGROUND

Bell Helicopter Textron, Inc. (BHTI) has a long term commitment to developing new composites technology. This has been most evident in the progress and changes in the manufacture of rotor blades. Composite components such as tail fins, litter doors, engine fairings, cowl panels, nose fairings, nodal beams, elevators, bellcranks, driveshafts, control tubes, and eventually a complete airframe now being designed for the Advanced Composite Airframe Program (ACAP), have further demonstrated BHTI's goals.

Composite fabrication methods presently in use at BHTI include filament winding, polar winding, hand layup, rapid ply cutting, autoclave and press laminating, bonding, and thermoforming. Pultrusion of fiber roving and fabric reinforced resin systems with subsequent postforming is a natural addition to these manufacturing methods.

3. PROGRAM PLAN

The program plan consisted of five tasks directed toward the development of a pultruded and postformed helicopter component and the fabrication and demonstration of the article.

3.1 TASK I - COMPONENT AND MATERIAL SELECTION

Determine the physical and mechanical properties of a component as presently produced and investigate a reinforcement/matrix combination which would lend itself to pultrusion and postforming.

3.2 TASK II - COMPONENT DESIGN

Design a replacement for the selected component in composite materials utilizing pultrusion and postforming to produce the final part configuration.

3.3 TASK III - SPECIMEN TESTING AND EVALUATION

Design and manufacture tooling for both the pultrusion and postforming of the candidate part. In addition, determine the proper pultrusion and postforming parameters to produce a satisfactory part. Fabricate test specimens of the representative geometry according to these parameters and test to ensure that the design and materials produce a reinformcement/matrix combination capable of meeting the property requirements of the current part.

3.4 TASK IV - FABRICATION OF HELICOPTER COMPONENT

Based on the results of Task III, fabricate a minimum of ten demonstration components by pultrusion and postforming. Perform static tests on some of the components to verify design performance. Additionally, compare the advantages and disadvantages of pultrusion/postforming fabrication as opposed to other methods of composite fabrication. Finally, prepare an analysis to determine the cost of fabricating 10, 100, and 1,000 production parts including materials, labor, tooling, and other costs with regard to the two methods of composite fabrication and the present door track. Issue a final report covering all of the work performed under the contract. Include detail descriptions for tooling fabrication, fabrication of the demonstration parts, testing, and all cost and economic analysis.

3.5 TASK V - INDUSTRY BRIEFING

Conduct an industry briefing for Army and industry personnel on the program in its entirety. Make available an Executive Summary at that time to briefly describe the program and the results.

4. RESULTS AND DISCUSSIONS

This program consisted of the following four tasks:

- Task I - Component and Material Selection
- Task II - Helicopter Door Track Design
- Task III - Specimen Testing and Evaluation
- Task IV - Fabrication of Helicopter Door Tracks

4.1 TASK I - COMPONENT AND MATERIAL SELECTION

The contract required that the demonstration article be an Army helicopter component that was presently being produced and could be fabricated from composites using pultrusion and subsequent postforming. Goldsworthy Engineering, Inc., Torrance, California was selected as the subcontractor for the pultrusion portion of the program due to their pultrusion knowledge, experience, and facilities.

4.1.1 Establish Component Requirements

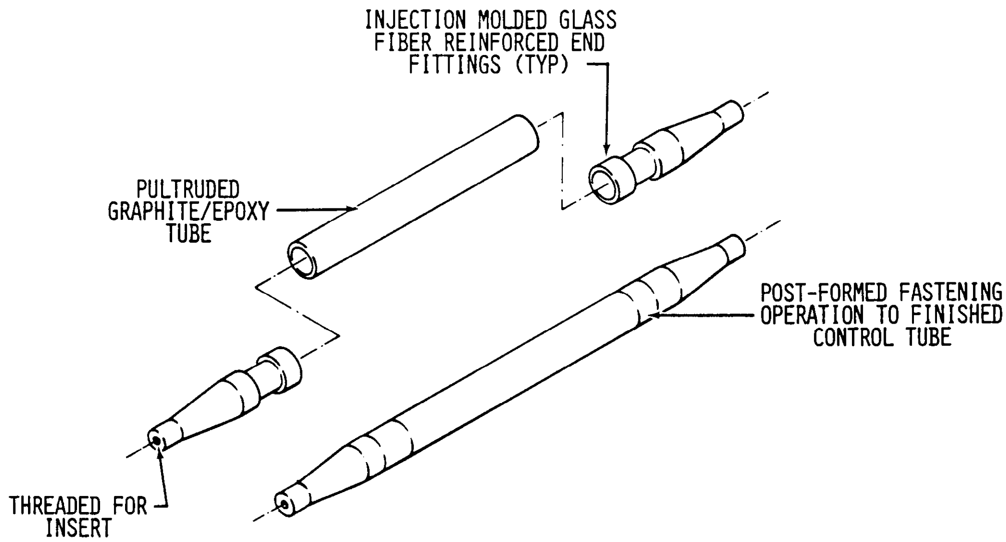
Components which had previously been established as potential candidates were: (1) the 214-801-041 control tube; (2) the 214-021-101 tailboom elevator spar; and (3) the 214-031-276 upper cargo door track. Preliminary concepts for these components are shown in Figure 4-1.

The control tube is considered as a primary structure and therefore was not a good part for the introduction of new technology.

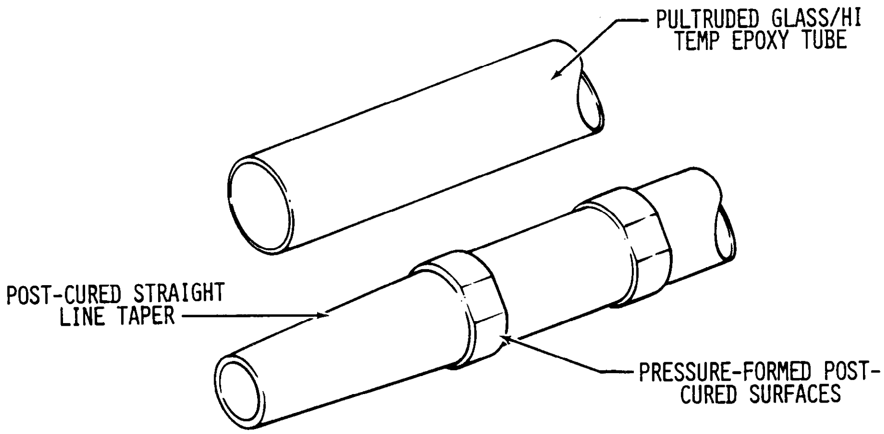
Secondary and supplementary operations requiring parts made by other methods discouraged the choice of the tailboom elevator spar. It was felt that these operations would alter the direction of the program.

The most feasible of the candidates was the upper cargo door track. It appeared to be postformable with minor secondary operations. However, it was discovered that the track carried all of the door weight and was considered as primary structure which eliminated it from the program.

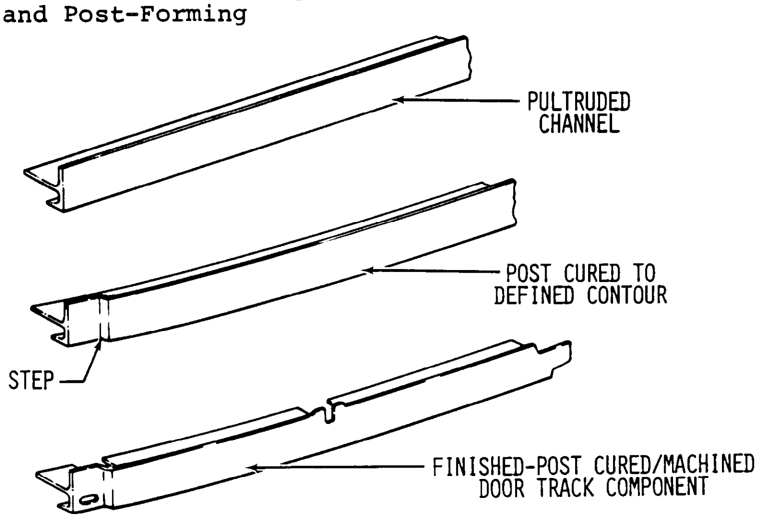
A new candidate was considered which had the required attributes. The 205-030-293 lower aft cargo door track (Figures 4-2 and 4-3) is used on the U.S. Army UH-1 helicopter (Figure 4-4). The part describes an arc 83 inches long with a 240-inch radius and a twist in the final 5 inches. A constant cross section (Figure 4-5) lends itself to pultrusion and the gentle curve to postforming. The upper cargo door track carries the weight of the door; therefore, the only significant flight load on the



A. Fabrication Concept for Control Tube Using Post-Formed Pultrusion Techniques



B. Tailboom Elevator Spar Fabrication Using Pultrusion and Post-Forming



C. Fabrication Concept for Door Track Component Using Post-Formed Pultrusion Techniques

Figure 4-1. Pultrusion and postforming candidates.

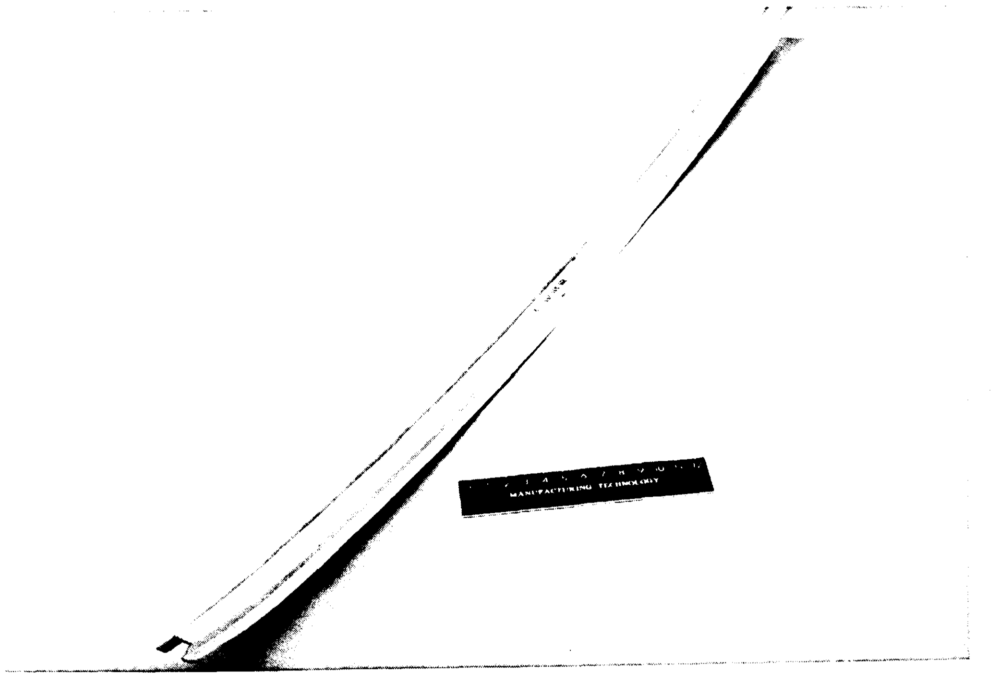


Figure 4-2. Model UH-1 helicopter cargo door track.

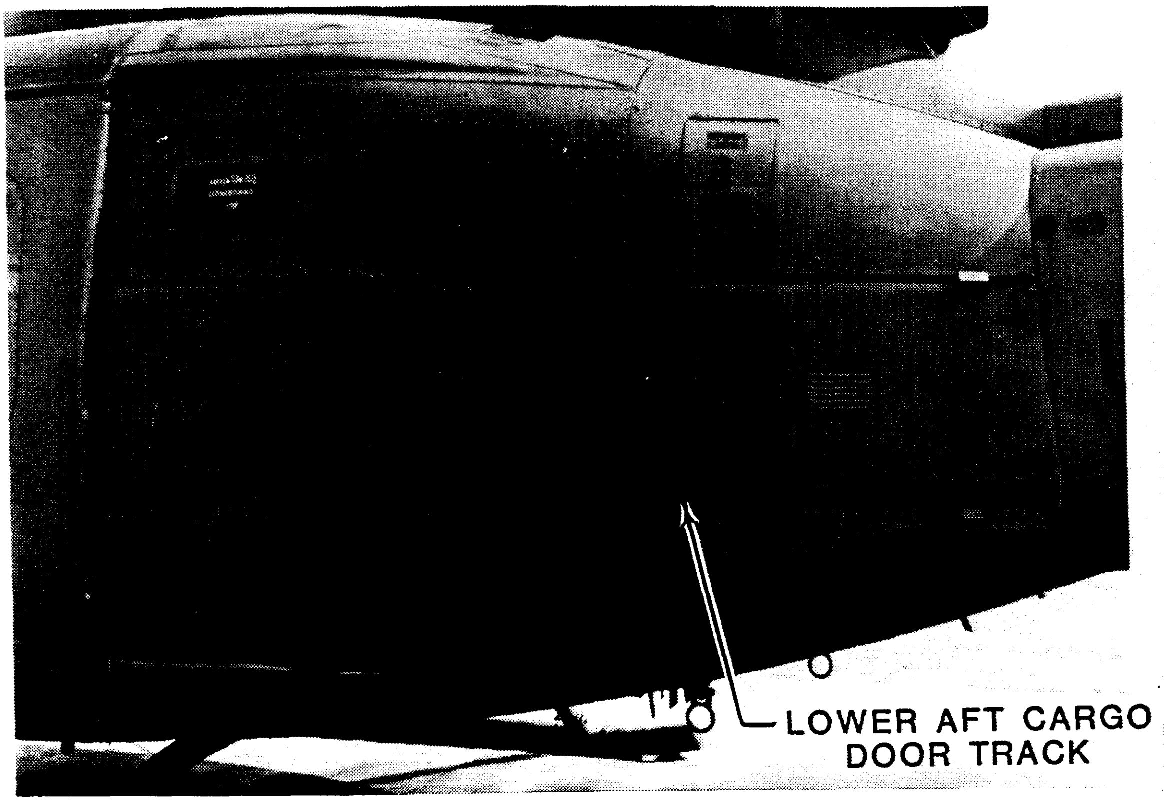


Figure 4-3. Fuselage section of UH-1 showing location of lower aft cargo door track.

Figure 4-4. UH-1 helicopter.

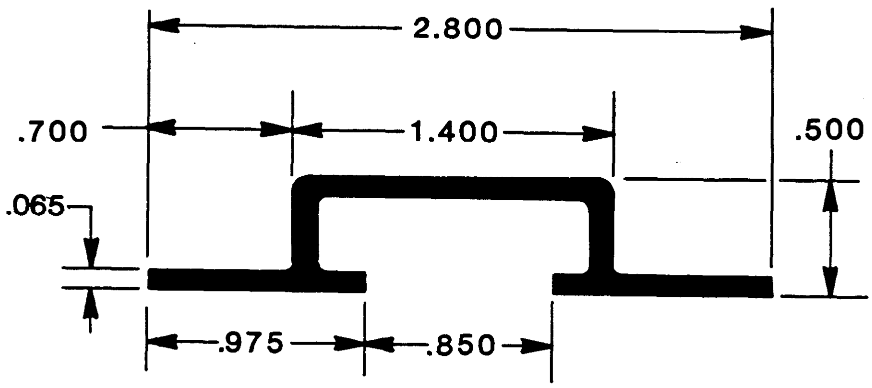


Figure 4-5. Aluminum door track cross section.

lower track was found to be introduced by the lower door mounting slides. This force was calculated at 80 pounds in an outward direction, perpendicular to the track face, which corresponds to a 0.345 psi air load on the door. This loading was regarded as well within the load limits of composite technology. The aluminum version of the track has been produced in the thousands so that substantial background information is available. Therefore, the part chosen as the demonstration article was the left lower aft cargo door track, #205-030-293-1, (Appendix A) as shown mounted on a fuselage in Figure 4-6.

4.1.2 Material Selection

The material selection was as critical as the part selection. While the shape of the part would determine the potential for pultrusion, the matrix material would govern the ability to pultrude and to postform the preform. The matrix material along with the reinforcement is responsible for imparting the final strength requirements. Therefore, the material had to form a stable B-stage cross section in the preform to permit handling without disturbing the cross section and yet be malleable for insertion into the postforming tool.

The pultrusion process offered the first hurdle because the state-of-the-art of the pultrusion industry did not lend itself to the production of B-stage materials. Virtually all materials are currently processed by wet pultrusion and cured at the die, providing a stable, finished product that need be only cut to length. As the vast majority of materials are fiberglass reinforced polyesters, vinylesters, or epoxies, the process produces a strong, economical, straight product suitable for industrial or consumer applications.

The initial tendency was to use a fiberglass reinforced epoxy due to BHTI's familiarity with the processing and properties of this type of material. Consultation with Goldsworthy personnel indicated that they did not anticipate any significant problems in achieving the cross sectional geometry of the preliminary door track designs with fiberglass/epoxy. They did feel that the inherent process restraints attached to epoxy pultrusion would limit the production rate to 2 - 3 inches/minute. An agreement was reached to evaluate alternative resins to determine whether a system was available to meet the requirements in a high production rate environment.

After a number of resins had been examined, ICI Americas' XPL 1056 vinylester was chosen as the candidate matrix material. The reasons for choosing this material are numerous. It has published properties approaching those of epoxies and can be pultruded at faster rates, 10 - 15 feet/minute. The resin cures extremely fast in 5 - 8 minutes at 285°F and has a thick-

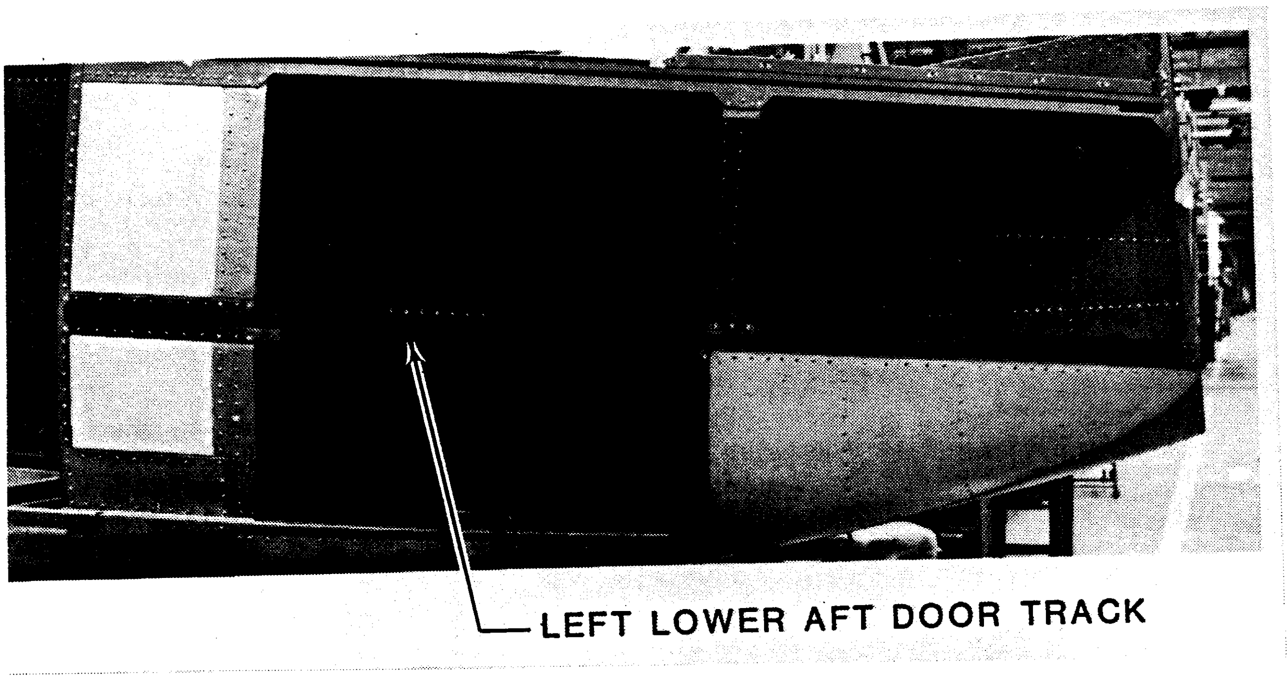


Figure 4-6. Left lower aft cargo door track during helicopter assembly.

ening stage somewhat similar to an epoxy B-stage, which allows a preform to have a shelf life of one year at 75°F when packaged in aluminum foil. This thickening stage, referred to as maturation, occurs because of the reaction between a polyisocyanate and a polyol, forming a urethane suspended in the vinylester. The reaction takes place in 24 hours at 75°F or can be accelerated by the addition of heat. The vinylester does not enter into the reaction process and is therefore fully available for the final cure.

A sample of the XPL 1056 was obtained (Figure 4-7) and test samples were prepared in the BHTI Materials Laboratory. Using the resin system as recommended by ICI, test panels were fabricated by winding Kevlar and fiberglass rovings around a 12- x 12- x 1-inch aluminum mandrel. One ply of release cloth was applied to the mandrel, then Kevlar or fiberglass rovings were wound with the resin applied after each complete wrap using a paint brush and worked in with a plastic squeegee (Figure 4-8). The windings were built up to approximate a 0.070-inch-thick panel on each side of the mandrel. The mandrel and windings were wrapped and sealed in aluminum foil for 72 hours at 75°F to allow the resin to maturate. Two 12- x 12-inch panels were then cut from the windings, laid on an aluminum plate, vacuum bagged, and autoclave cured. The cure cycle was 15 minutes in a preheated autoclave at 290° ±10°F under vacuum and 95 psi autoclave pressure.

Two panels of 20-end-count Kevlar roving were prepared in this manner, one using Kevlar predried for 24 hours at 150°F.

Additionally, one panel each of S-2 fiberglass roving, 60- and 20-end-count respectively, were produced along with one panel fabricated of 2 inner plies of 120 weave E-glass fabric, three windings of 60-end-count S-2 glass roving, and 2 outer plies of 120 weave E-glass fabric. This last fabrication approximated the initial design concept.

Tensile and flexural test specimens were cut in the 90° direction from all of the panels. In addition 0° specimens were prepared from the fabric/roving/fabric panel. All specimens were prepared according to Figure 4-9 and tested per Federal Test Method 1011, Standard 406 (Tensile Properties) and Method 1031 (Flexural Properties).

Test results for the specimens are shown in Table 4-1. The internal material procurement specifications of BHTI were used as a comparison with no intention of using them as a requirement. There are no flexural values in the specifications, so these values were only used in comparison with each other.

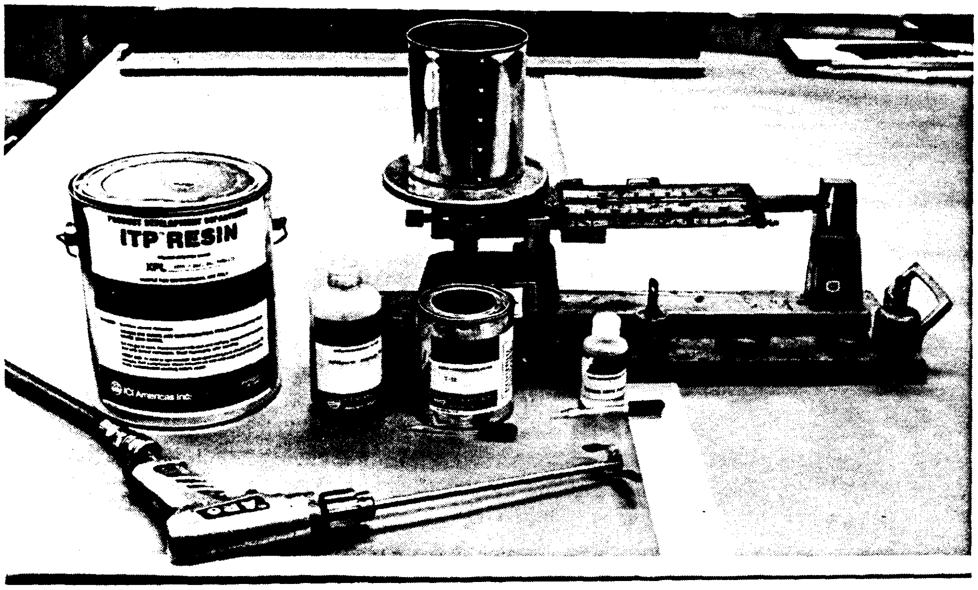


Figure 4-7. ICI Americas' XPL 1056 vinylester.

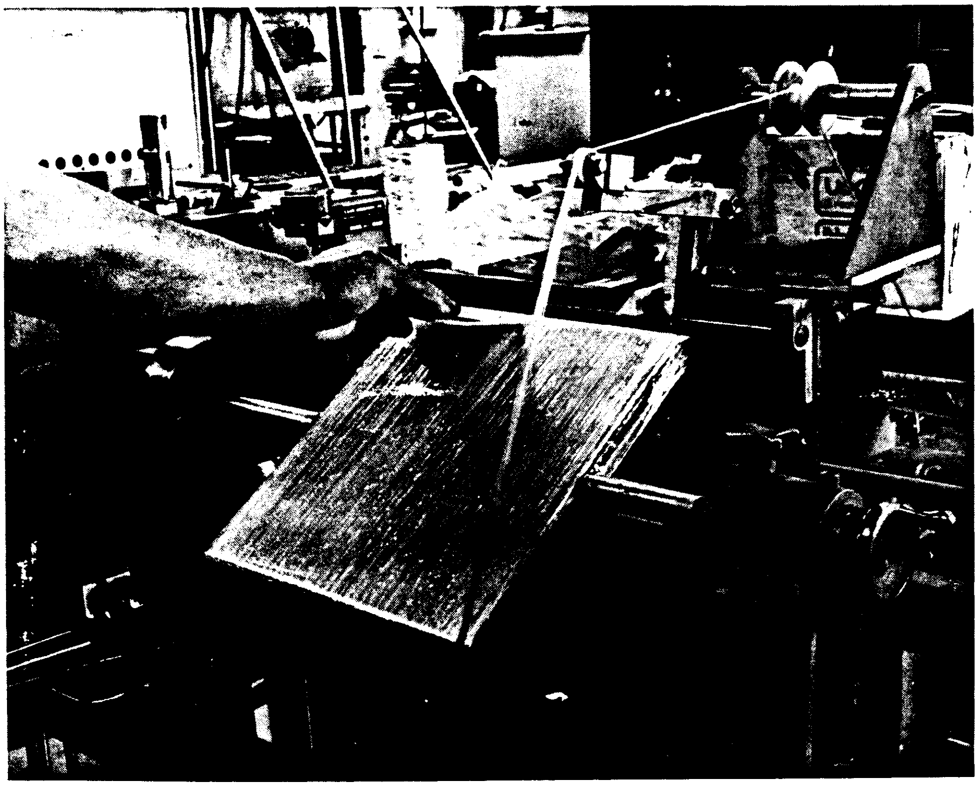


Figure 4-8. Application of vinylester resin to roving.

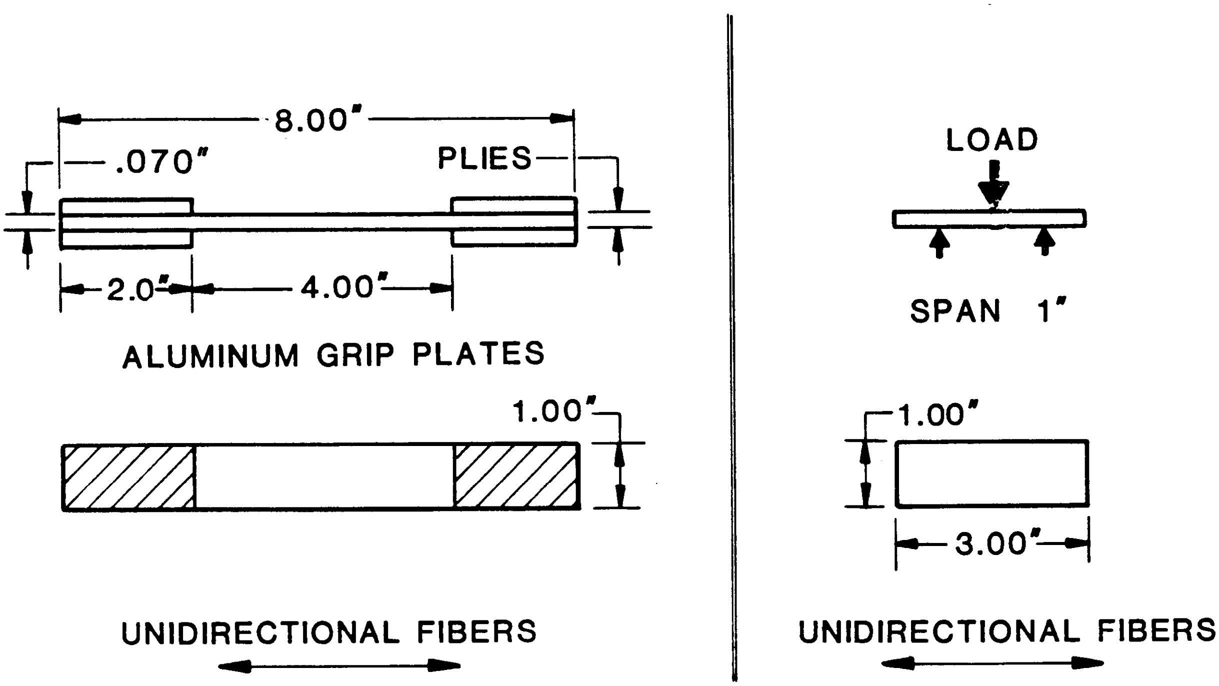


Figure 4-9. Typical tensile and flexural test specimens.

TABLE 4-1. 75°F TEST RESULTS FOR FIBER REINFORCED/ VINYLESTER SPECIMENS

Specimen	Mean Tensile (psi) Strength		Mean Flexural (psi) Strength	
	90°	0°	90°	0°
Fabric/Roving/Fabric-Dry	8,723	74,961	34,908	98,577
Fabric/Roving/Fabric-Wet 72 Hr H_2O soak at 125°F	8,902	NT	34,112	NT
Kevlar Roving	1,425	NT	4,011	NT
Kevlar Roving - Dried 24 Hrs at 150°F	1,570	NT	3,550	NT
S-2 Roving, 20 end count	3,702	NT	6,596	NT
Bell Spec. 299-947-164 Kevlar/Epoxy Tape	1,250	NR	NR	NR
Bell Spec. 299-947-134 Fiberglass/Epoxy Tape	6,000	NR	NR	NR

NT - Not tested
NR - Not required

The Kevlar roving in both the dried and undried states exceeded the Kevlar specification values and indicated that the material need not be dried when used with the vinylester. The S-2 roving, 20 end count, did not come up to the level of the BHTI fiberglass specification and the S-2 roving, 60 end count was too thick for reliable test results. The fabric/roving/fabric composite samples were dried for 72 hours at 140^{O}F. Half of the samples were then subjected to a 72 hour soak in 125^{O}F water. In both the dry and wet states the composite easily passed the arbitrary BHTI specification values shown in Table 4-1.

From all appearances, the XPL 1056 was the matrix material to design a composite door track around if it could be pultruded. This was to be confirmed or discounted in the pultrusion trials of 4.3.3.

4.2 TASK II - HELICOPTER DOOR TRACK DESIGN

The intent of this task was to develop the final design of the composite helicopter door track around a matrix combination chosen from those investigated in 4.1.2 and determine the applicable attachment method.

4.2.1 Door Track Design

A dimensional duplicate of the metal door track was regarded as feasible based on the data generated in 4.1.1 and 4.1.2. The only exception was an increase in the wall thickness of 0.005 inches to 0.070 inches for additional strength (Figure 4-10). The fabric/roving/fabric vinylester composite appeared substantial enough to bear the 80 pound load described in 4.1.1. To test this concept, 0^{O}flange test specimens were removed from the fabric composite panel fabricated in 4.1.2 and mounted in a test fixture (Figure 4-11). An aluminum slide was used to load the resulting flanges with weights to simulate in-flight loading. The flanges broke at 434 pounds indicating a safety factor of 5.5 to 1. Recognizing that it would be difficult to pultrude two plies of 120 style E-glass fabric, the overwrap was changed to 1 ply of 7781 style E-glass fabric to provide transverse strength. The resulting E-glass/vinylester, S-2 glass/vinylester, E-glass/vinylester, composite was judged to to meet the mechanical requirements of the demonstration track through the range of -67^{O}F to 165^{O}F at 85 percent relative humidity. The loading requirement was set at 89 pounds to allow a 10 percent safety factor and the wear test at 200,000 cycles to reflect door opening and closing. The final design, #599-603-001, is shown in Appendix B.

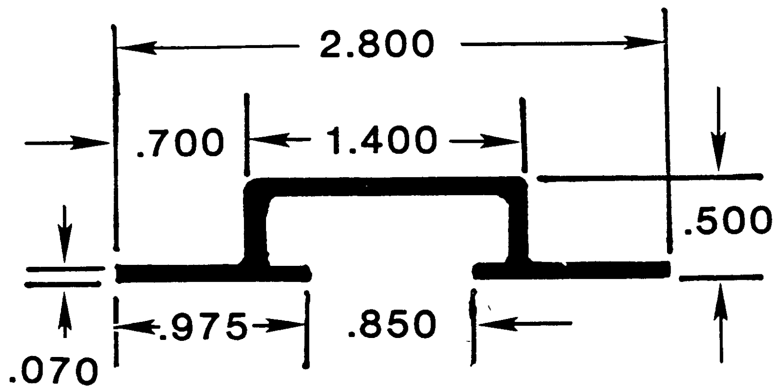


Figure 4-10. Cross section of pultruded composite door track.

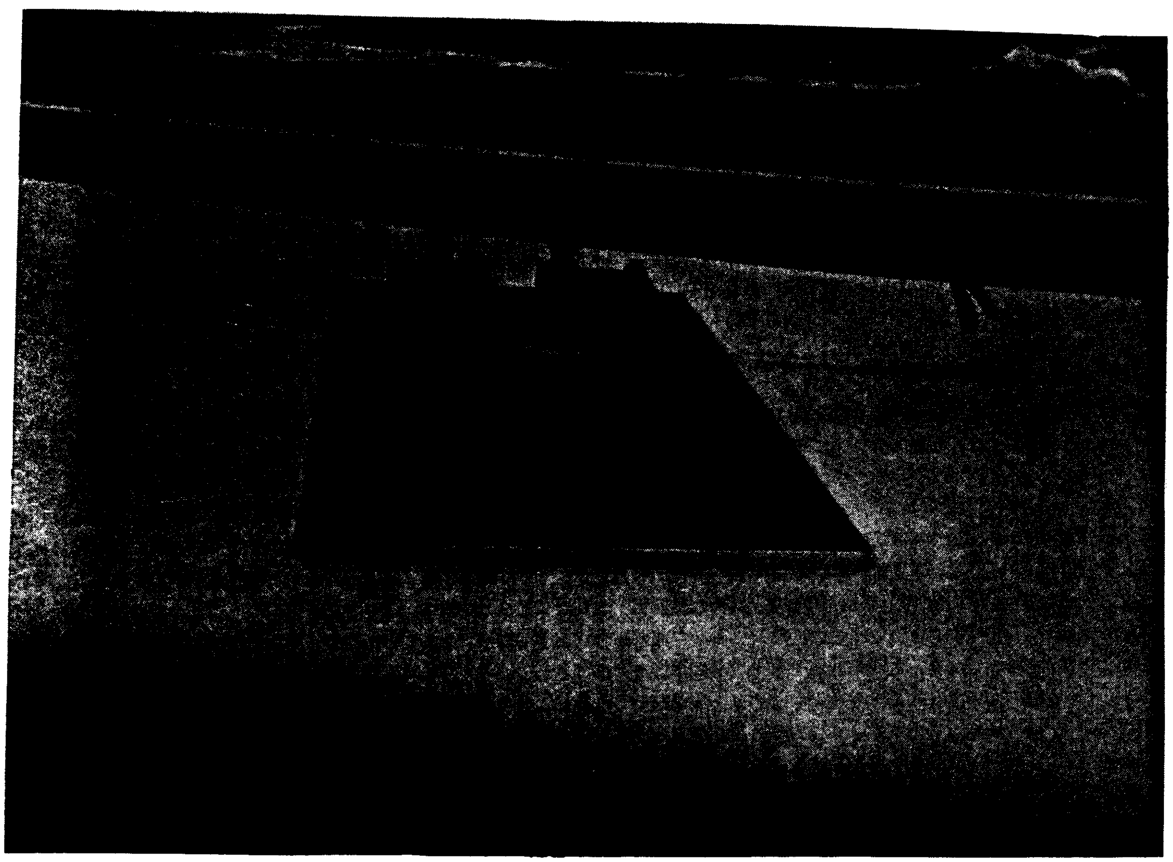


Figure 4-11. Lip load test arrangement upside down to show slider and cable.

4.2.2 Attachment Design

Conventional riveting was investigated as the primary method of attaching the composite door track to the fuselage. 0.375-inch-diameter holes were drilled through a flange specimen and aluminum. The two materials were then attached with a counter-sunk rivet and examined for delamination (Figure 4-12). Surface delamination of the composite was negligible or nonexistent. The attached materials were not laboratory tested but appeared extremely strong when tested by hand. Since no specification exists for this attachment combination, it was concluded that riveting would satisfy the attachment requirement. Consequently, a typical installation drawing was prepared, #599-603-002 (Appendix C).

4.3 TASK III - SPECIMEN TESTING AND EVALUATION

This task was the most encompassing of all. It included designing and fabricating both the pultrusion and postform tooling in addition to establishing the pultrusion and postform processing parameters. Sample production and testing were also originally included in this task but due to pultrusion problems were moved into Task IV.

4.3.1 Postform Tool Design and Fabrication

The postform tool was designed around the existing door track as a self-pressurized mold consisting of a male base with a female upper half. A rubber bun was designed to act as an internal pressure mechanism to maintain the dimensions of the inner flanges. A typical cross section of the tool is shown in Figure 4-13.

An untrimmed metal door track was used as a pattern. The track was stabilized by attaching it to a metal plate as shown in Figure 4-14. A perfect sugar pine plank (Figure 4-15) was sculpted and filled with Ren Plastics' RP 1220 epoxy to form the base for the metal plate. After mounting the track and plate on the base, the fabrication was coated with Release-All 50 mold release and polyvinyl acetate.

A TAFA Arc Spray 375 EFS Gun (Figure 4-16) was used to spray deposit a 0.020 inch layer of Tafaloy 204 zinc alloy on the pattern. The Tafaloy 204 is a hard surface material similar to Kirksite and being quite expensive, was backed up by a sprayed layer of pure zinc 0.060 inch thick. The sides of the pattern were built up with plywood and a thin graphite/epoxy gel coat containing 3mm graphite fibers was painted on the metal spray. A fiberglass/epoxy ladder was fabricated as a reinforcement (Figure 4-17) and placed on the gel coat (Figure 4-18). The cavity was then filled with TAFA 4350A graphite/epoxy containing

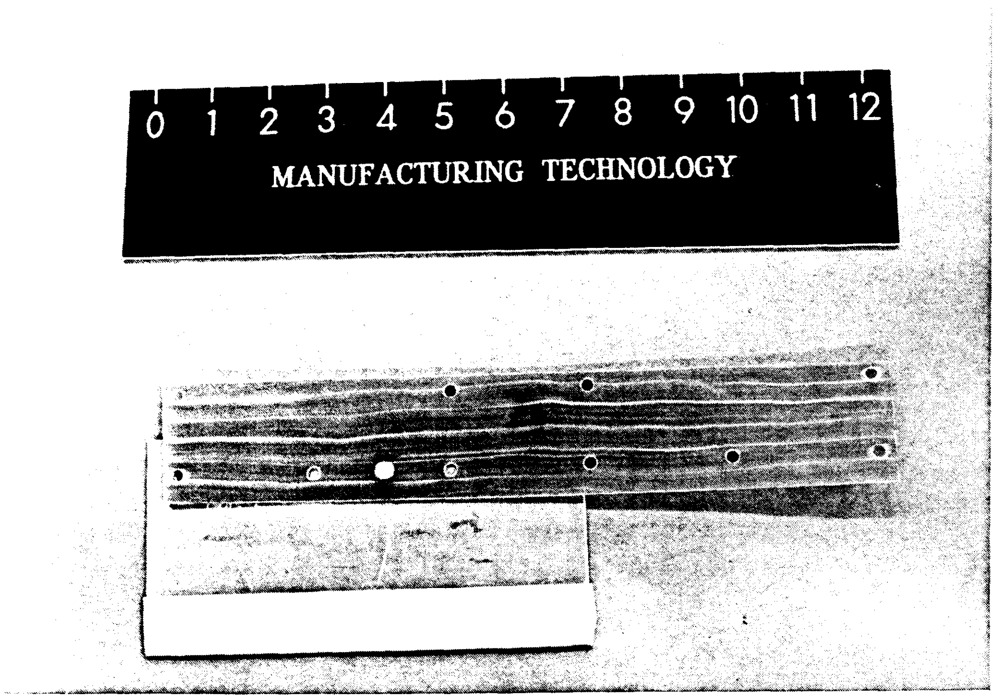


Figure 4-12. Countersunk rivet attachment of composite flange to aluminum.

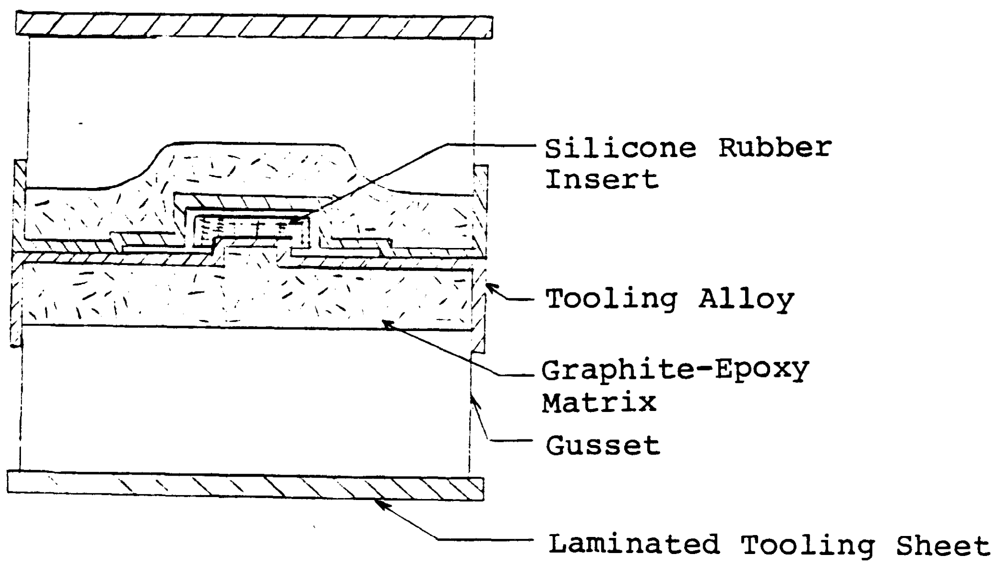


Figure 4-13. Typical cross section of complete mold box structure.

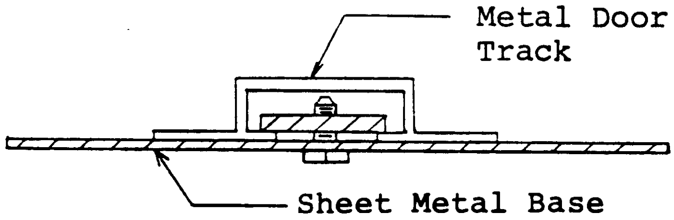


Figure 4-14. Metal door track stabilization.

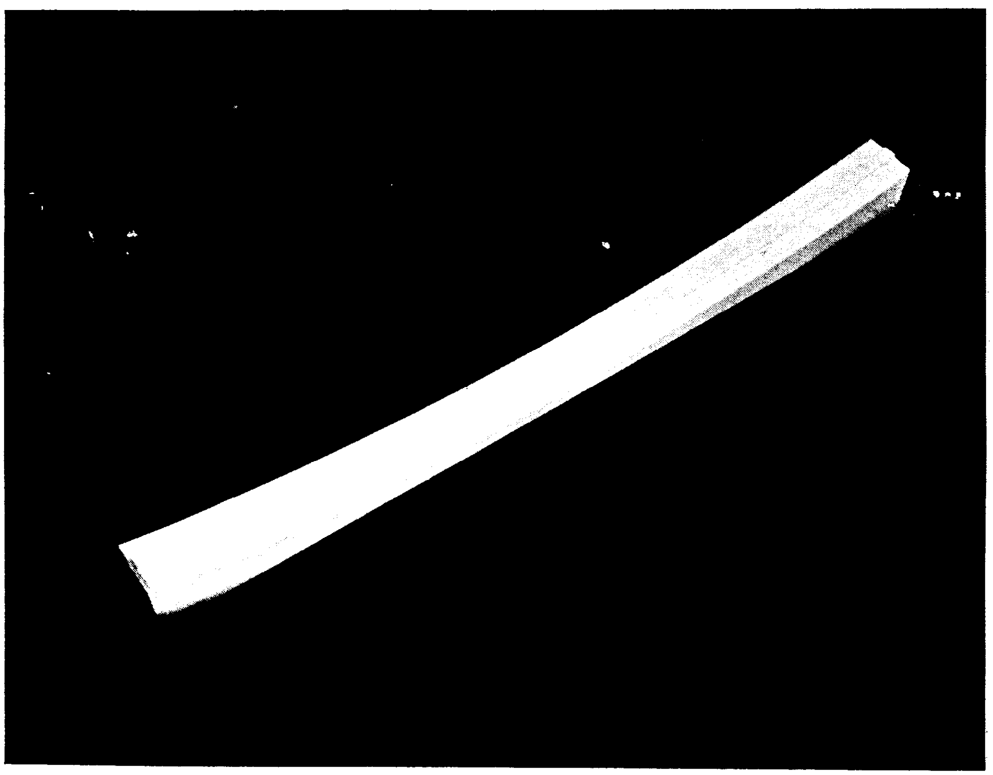


Figure 4-15. Sculpted pine plank for attaching metal door track pattern.

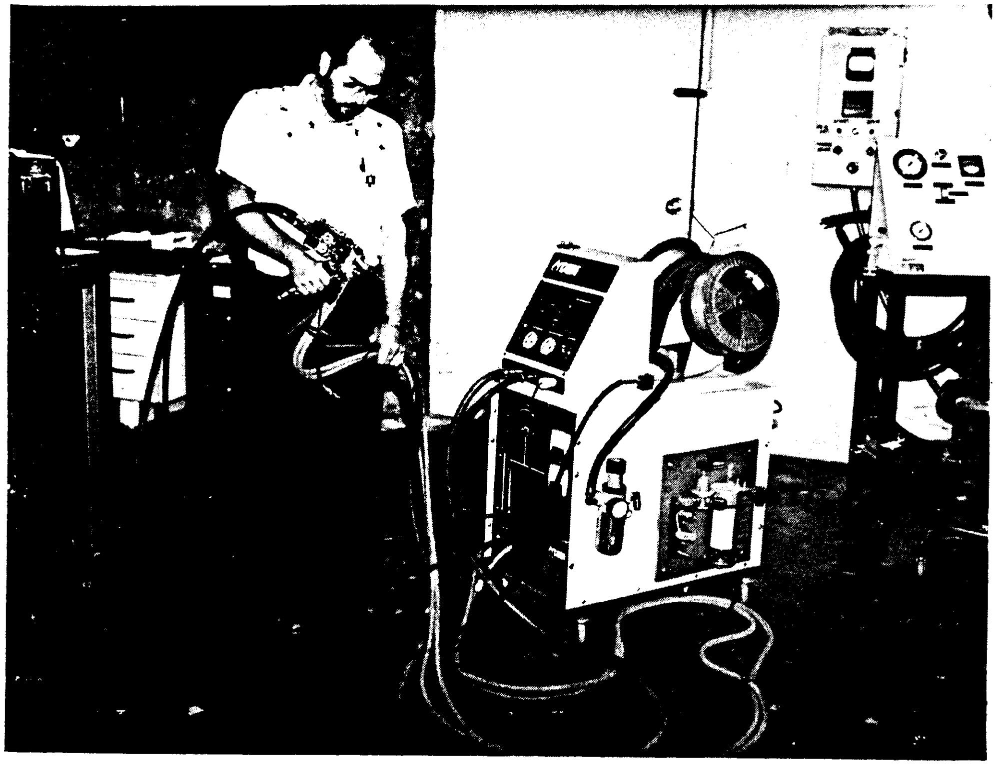


Figure 4-16. TAFA arc spray 375 EFS gun.

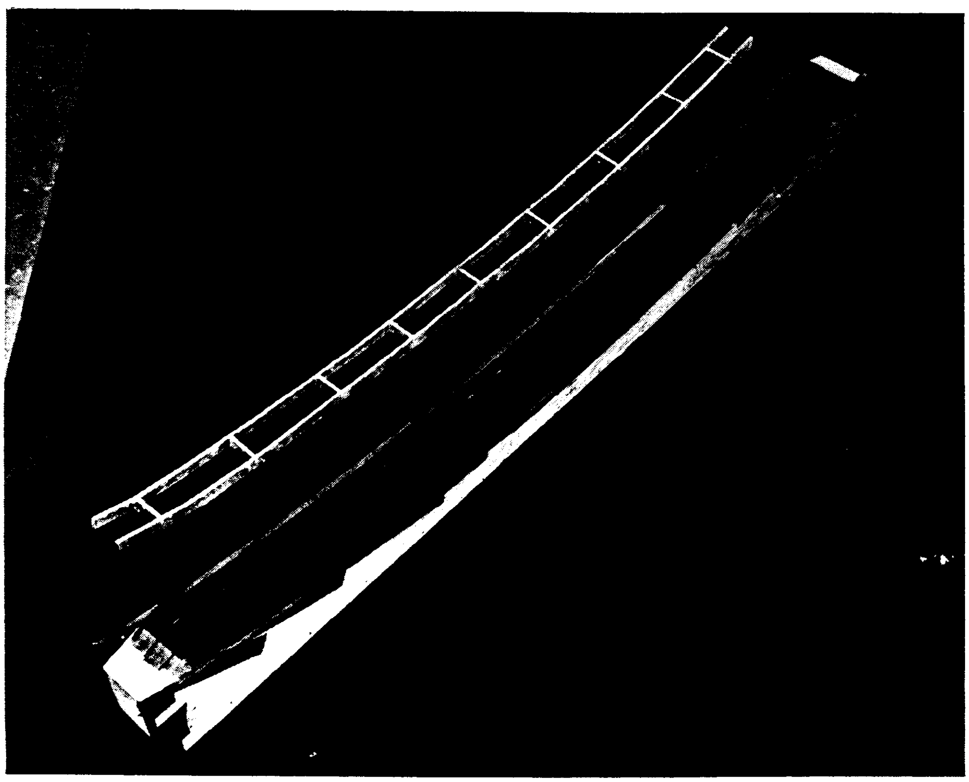


Figure 4-17. Fiberglass/epoxy reinforcement ladder and boxed pattern.

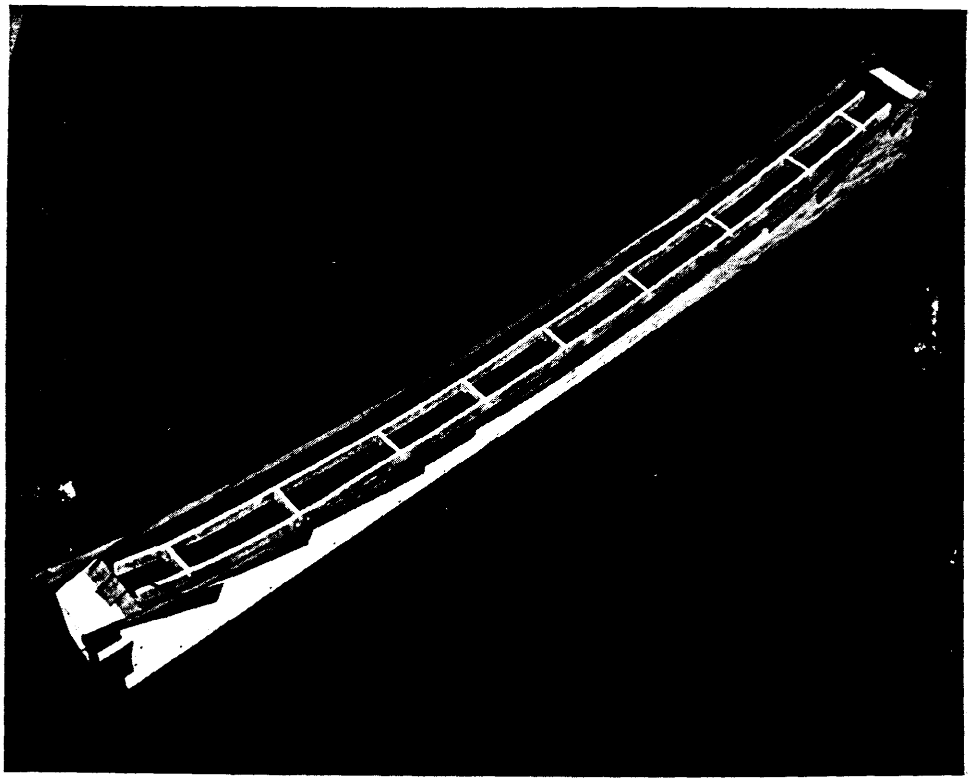


Figure 4-18. Fiberglass/epoxy ladder on gel coat.

0.25-inch graphite fibers. The tool layup was cured on the pattern for 24 hours at 75°F, then postcured in 2 hour steps in 50°F increments, from 150°F to 350°F for a total postcure of 10 hours. The female tool and pattern are shown before parting in Figure 4-19 and after disassembly and metal door track removal in Figure 4-20.

The male half of the tool was fabricated by mounting the metal door track in the female tool and filling the track interior with compound to the bottom of the internal flange. From this point on, all of the subsequent operations from the application of release agents through postcuring were the same as for the female tool. Epoxy legs were mounted on the male half for support during curing. The finished halves are shown in Figure 4-21 along with the metal door track.

A silicone rubber bun was constructed of Dow Corning's RTV Silastic E and cured for 24 hours at 75°F resulting in a product with a 40 durometer Shore A hardness. This was believed sufficient to stabilize the internal flanges during cure.

The male and female halves were then drilled to accommodate 0.50 inch bolts for positive pressure during oven postforming and curing. This eliminated the requirement for autoclave curing.

Initial 13-inch-long test samples of pultruded fiberglass/epoxy were postformed and cured in the tool. In all cases the metal surface of the tool pulled off during sample removal (Figure 4-22). It was determined that the surface was not conducive to epoxy curing and could not be repaired after each cycle, therefore a new tool would have to be designed and fabricated.

The second tool design was more conventional and consisted of a fiberglass/epoxy female with a removable support, an aluminum caul plate and a rubber bun. The design of the female portion is shown in Figure 4-23. The fabrication was a simple layup using Hexcel's Epolite 2354 epoxy tooling compound and fiberglass fabric. The metal door track was mold released and painted with a light layer of gel coat. Two plies of 120 fabric and 3 plies of 181 fabric saturated with resin were applied and placed under vacuum to remove entrapped air.

Eleven additional plies of resin saturated tooling fabric were then laid down with vacuum pressure applied after each six plies. The final tool was 0.375 inch thick over the crown of the hat section and contained 40 percent resin by weight.

A support was made for the tool for ease of part fabrication and used for the postcure. Curing consisted of 72 hours at 75°F, 2 hours at 200°F, and 3 hours at 325°F, all with the metal

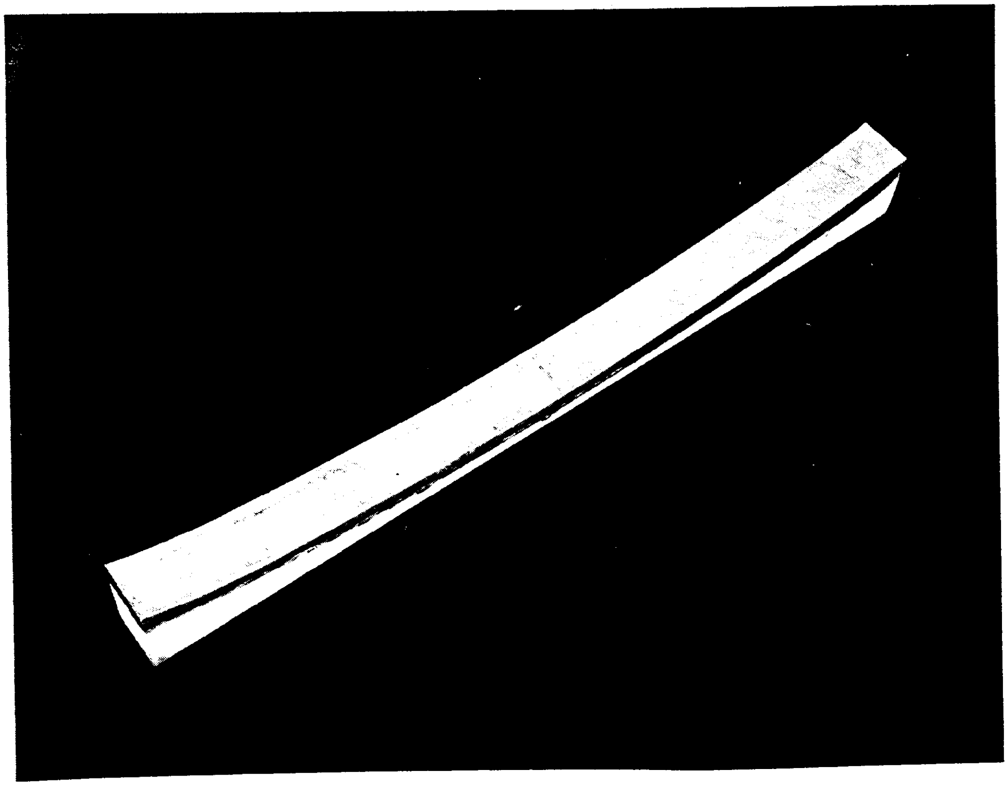


Figure 4-19. Female tool and pattern before parting.

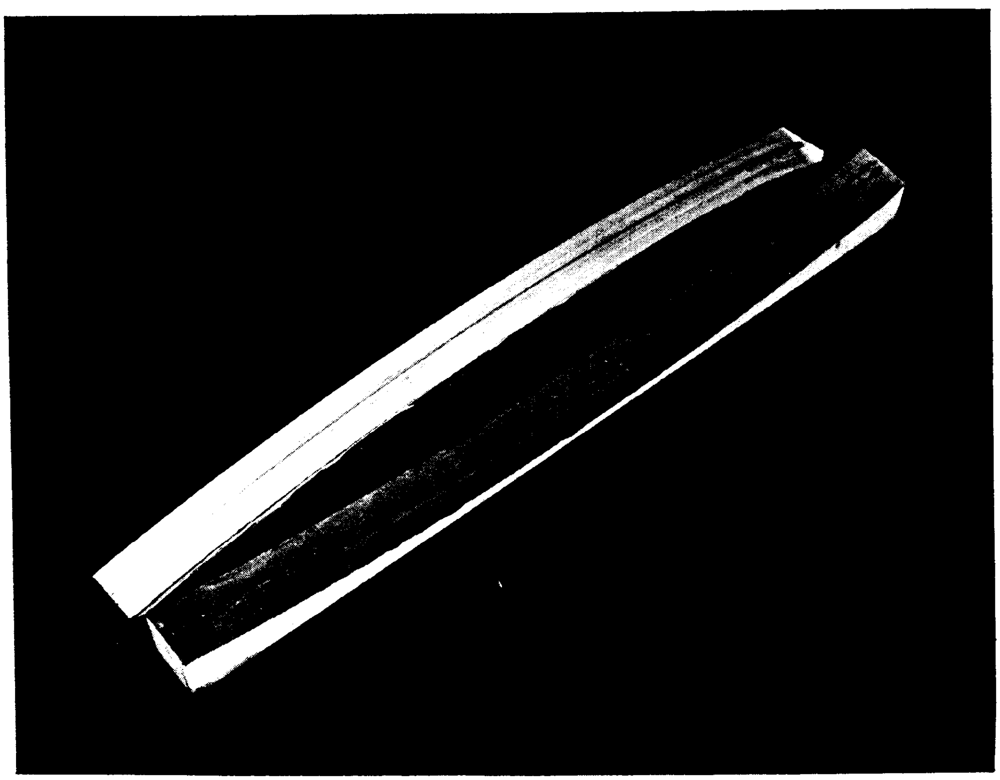


Figure 4-20. Female tool and pattern disassembled with metal door track removed.

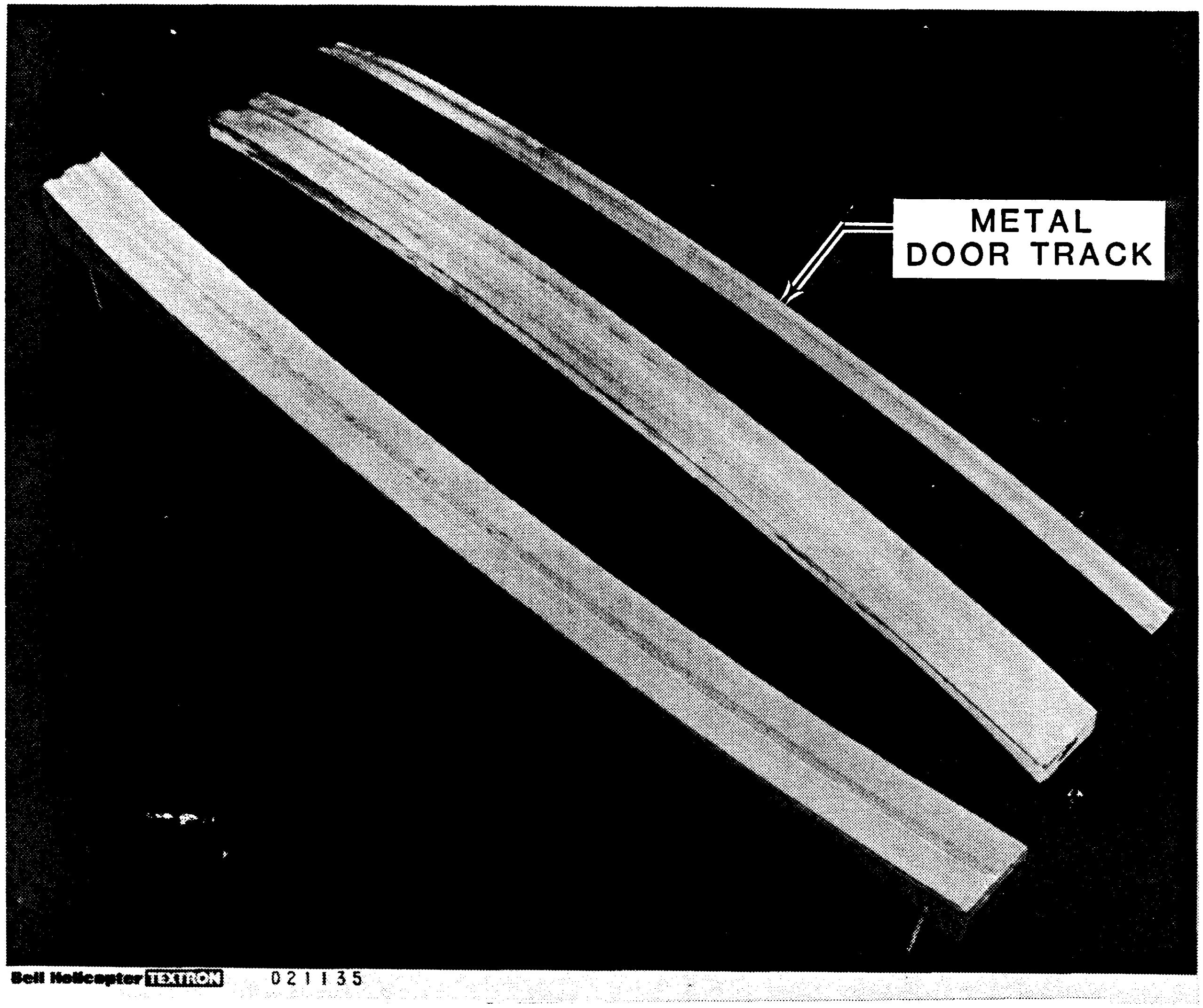


Figure 4-21. Finished tool halves and metal door track.

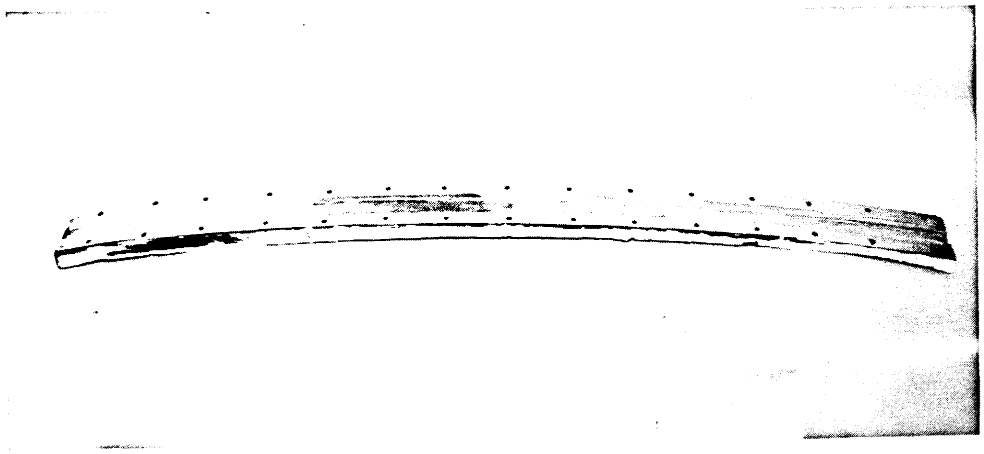


Figure 4-22. Metal tool surface pulled off during sample removal.

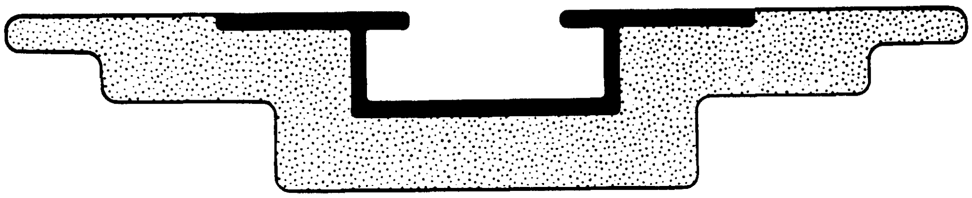


Figure 4-23. Fiberglass/epoxy postforming tool design.

track still inserted. The finished female tool and support is shown in Figure 4-24. A close view of the aft end incorporating the twist is shown in Figure 4-25.

The earlier rubber bun did not appear firm enough to provide the required pressure. 'D' Aircraft's Dapocast #37 silicone rubber was cast in the metal door track. The material was cured 24 hours at 75°F and then oven cured for 4 hours at 250°F and 4 hours at 350°F. The resulting bun had a 55 durometer Shore A hardness.

The final part of the tool was a 0.125-inch 2024-T3 aluminum caul plate which was roll formed to the contour of the tool face.

4.3.2 Pultrusion Tool Design and Fabrication

The design and fabrication of the pultrusion tooling was part of Goldsworthy's subcontract. The pultrusion was to be attempted with XPL 1056 vinylester resin and fiberglass, therefore a heated die was designed and built according to Goldsworthy Drawing T-51402 (Appendix D). The 30-inch long, three-piece die of plated steel is shown in cross section in Figure 4-26.

4.3.3 Pultrusion Parameters

The pultrusion processing parameters were more complex than anticipated due to the problems encountered with the vinylester, liquid epoxy, and epoxy prepreg.

4.3.3.1 Vinylester Pultrusion. Goldsworthy's laboratories were used for all pultrusion work. The setup for wet pultrusion of the XPL 1056 vinylester is shown in Figure 4-27. The creels were loaded with 60 end count S-2 fiberglass roving. The roving was passed through the vinylester bath and into steel tubing to separate the roving and prepare it for entrance into the die as in Figure 4-28. The fabric, 181 weave E-glass, was cut into four pieces and introduced into folding tooling to cover the glass rovings. In Figure 4-29, the fabric and rovings are shown entering the die with additional rovings being introduced at a 45° angle to fill out the die. For this trial, 97 rovings were introduced with the die temperature set at 300°F. The intent was to produce a cured vinylester track to determine if the parameters were correct. As shown in Figures 4-30 and 4-31, the track exited the die looking exactly as the cured part was envisioned.

The next step was to pultrude the maturated preform. The die heat was reduced to 225°F and the previous run duplicated at 3 to 6 inches per minute corresponding to a heated dwell time of

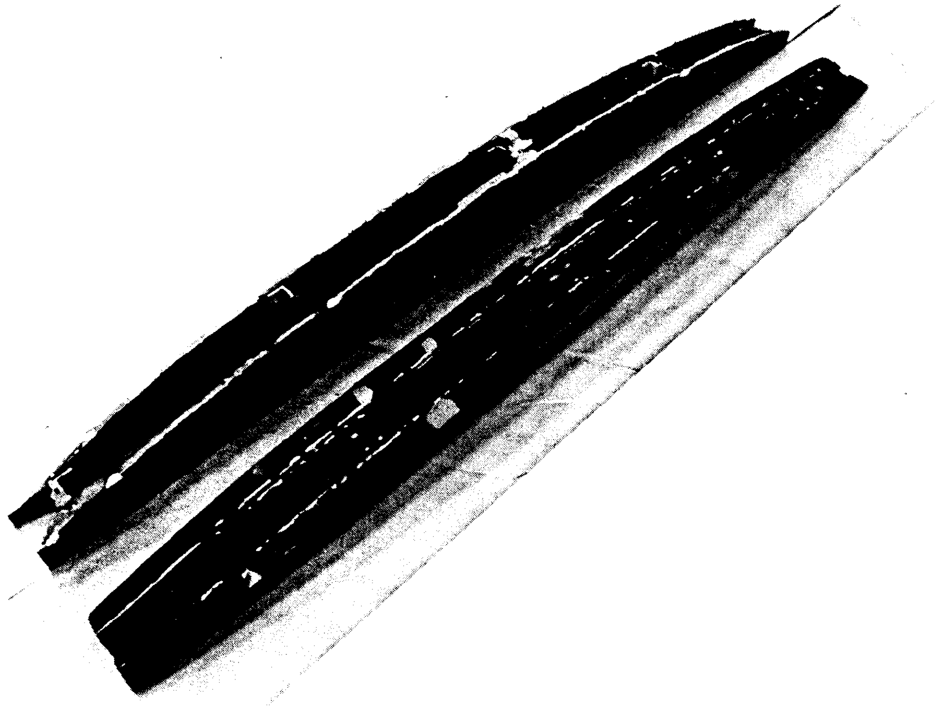


Figure 4-24. Female tool and support.

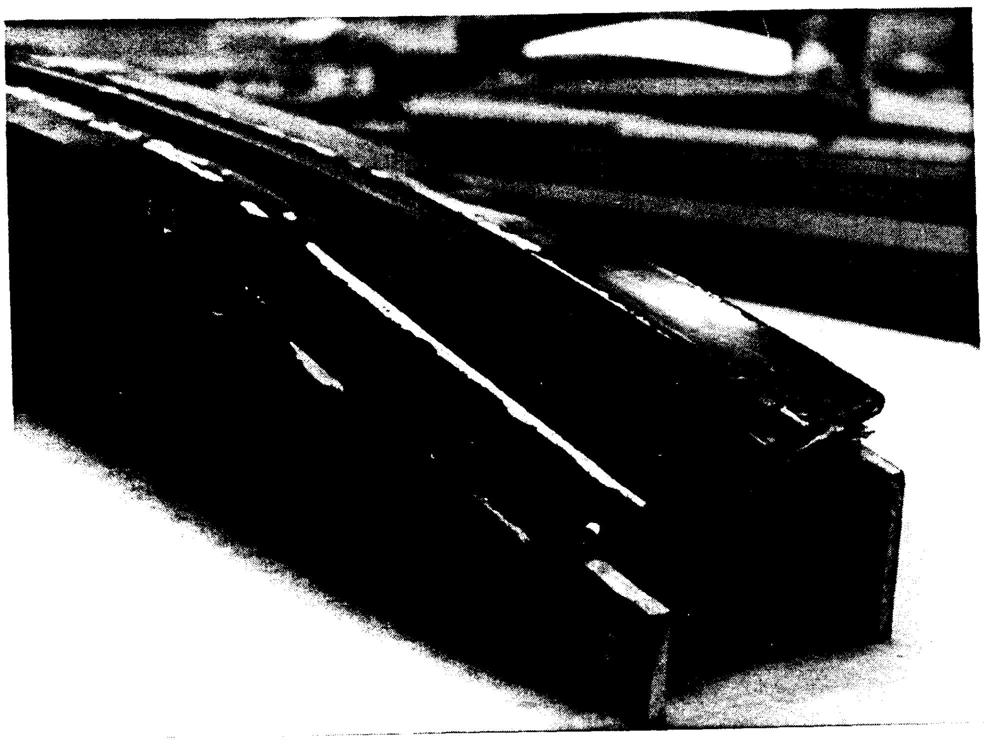


Figure 4-25. Closeup of postforming tool aft end incorporating twist.

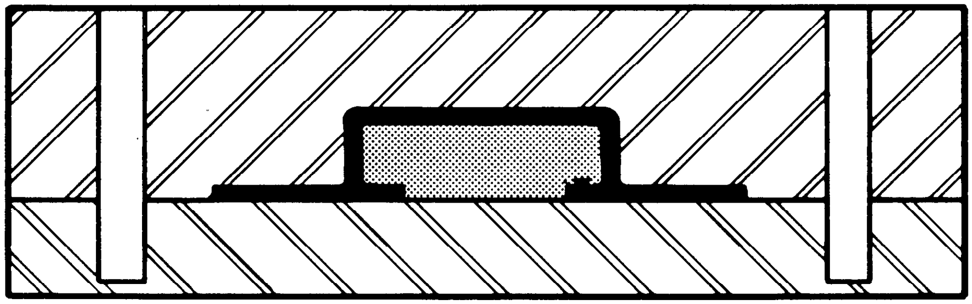


Figure 4-26. Pultrusion die cross section.

Figure 4-27. Goldsworthy's wet pultrusion setup.

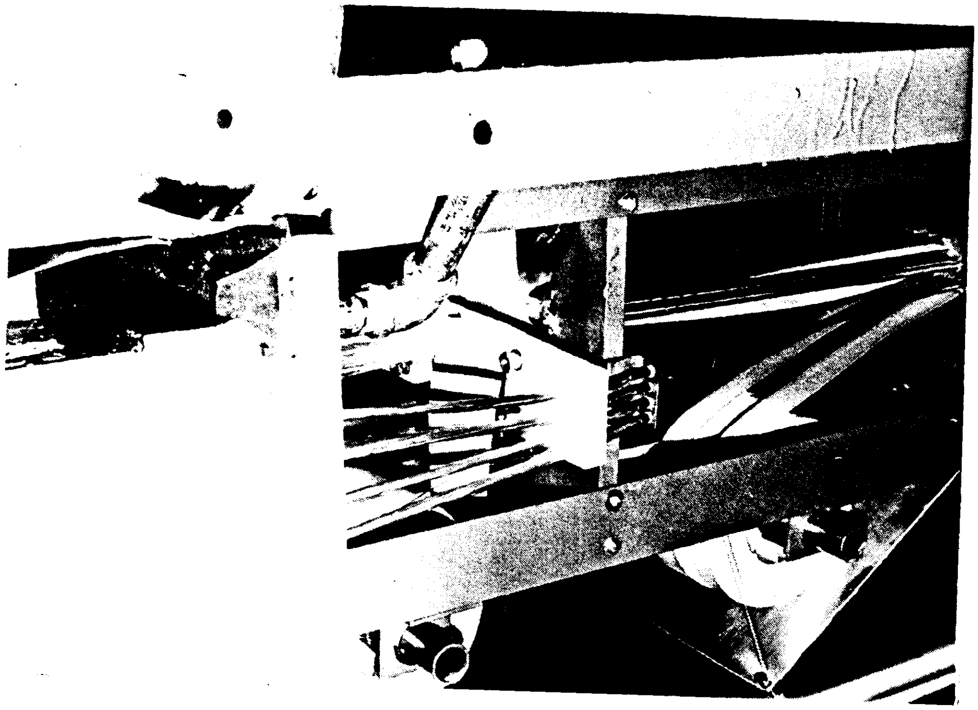


Figure 4-28. Roving exiting vinylester bath into steel tubing.

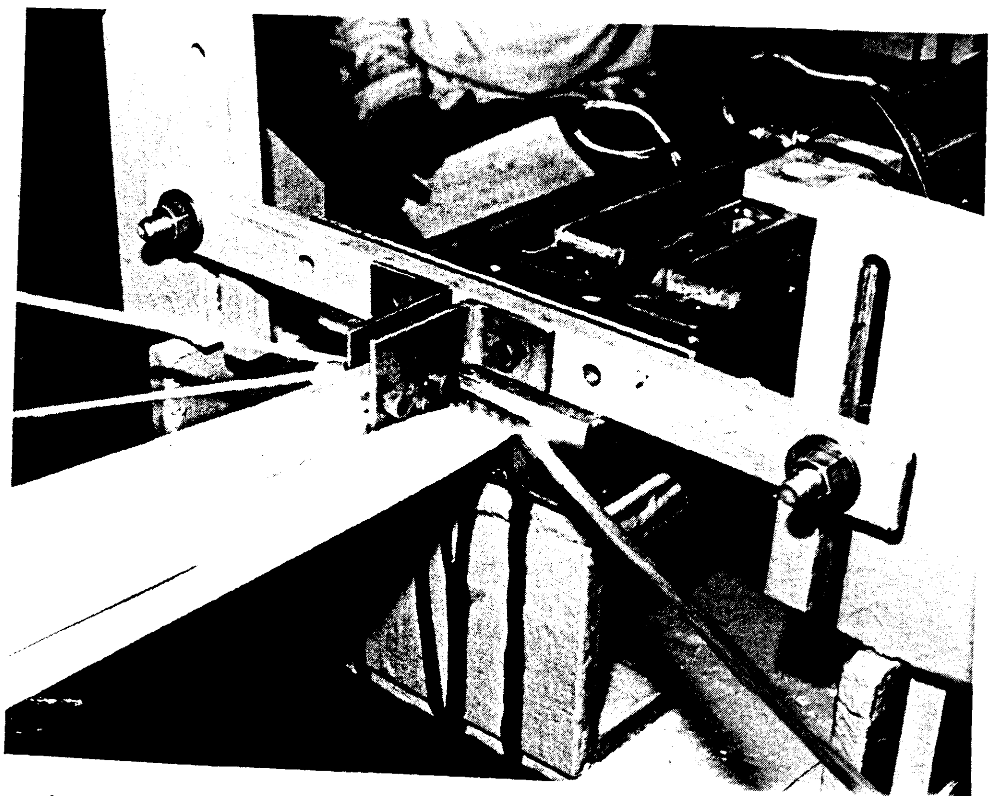


Figure 4-29. Fabric and rovings entering die.

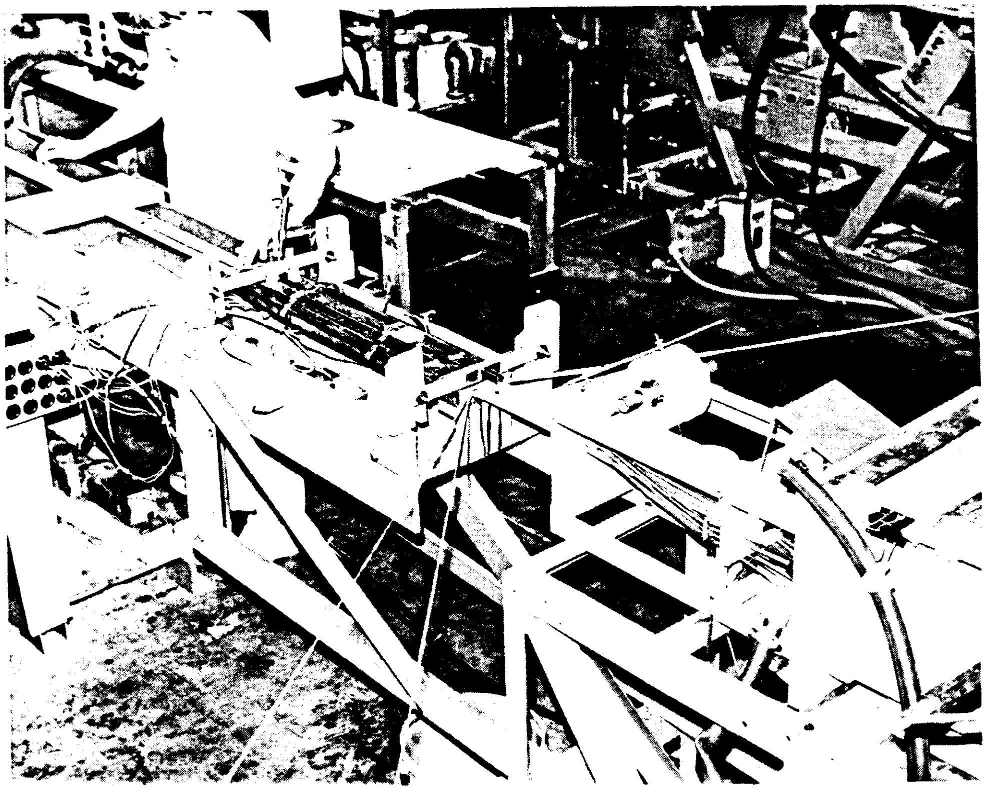


Figure 4-30. Pultruding vinylester door track.

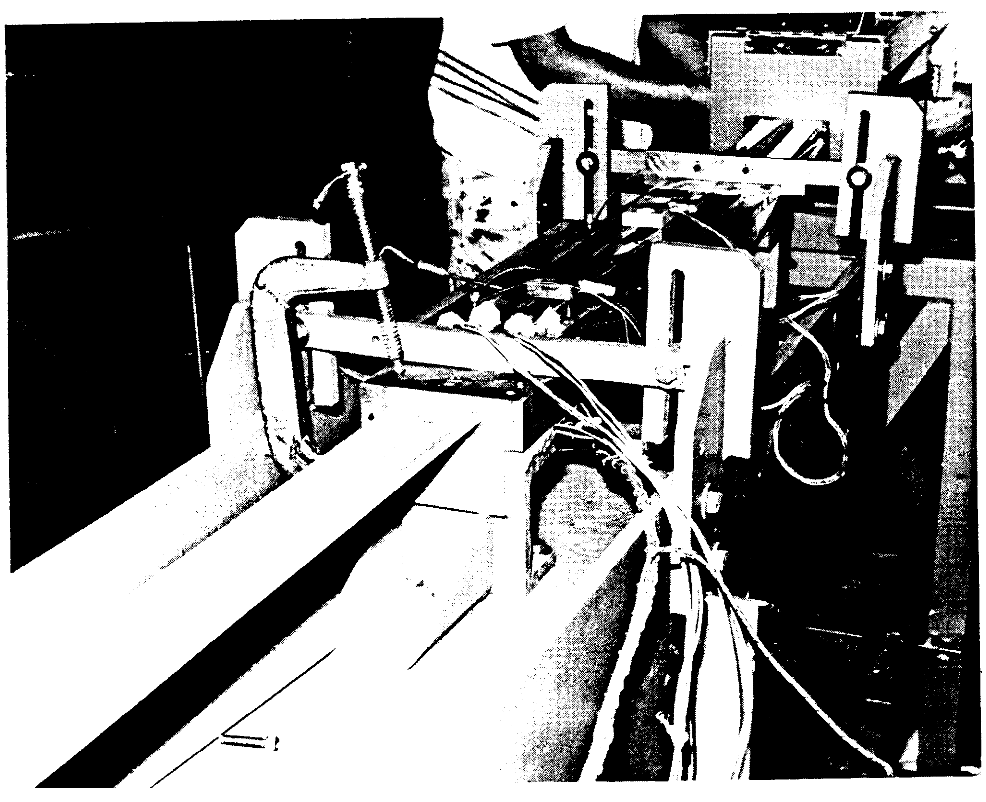


Figure 4-31. Cured vinylester door track exiting die.

5 - 10 minutes. Maturation was achieved, but some polymerization of the vinylester resin occurred. Varying the speed and temperature did not alleviate the problem. The maturation state was of a gel-like consistency which would not hold the roving and fabric together. In addition, the pulling loads exceeded 6,000 pounds even with the addition of hydrate of alumina for viscosity control. The pot life of the vinylester was 1 to 1-1/2 hours which was far too short for continuous pultrusion runs. All of these deficiencies in the vinylester system precluded the use of the system in this state. ICI Americas was contacted regarding reformulation. They felt that this could be accomplished resulting in a usable product, but the timing was far beyond the scope of the project. The time constraints led to the decision to use an epoxy system familiar to BHTI personnel, U.S. Polymeric's E773.

4.3.3.2 Wet Epoxy Pultrusion. The U.S. Polymeric E773 cures fully at 250°F. Polymerization starts at 200° - 220°F and proceeds to completion without passing through a B-stage. The product required for a preform would be a hot-melt, hard at 75°F and soft and flowing at elevated temperatures. This could be accomplished by keeping the pultrusion temperatures of the E773 below 180°F allowing long working periods. For trial purposes, 130 pounds of 70 percent solids E773 solution were purchased from U.S. Polymeric.

The feed and folding system used for the vinylester was kept intact. The S-2 rovings were wet in the bath as shown previously and the various layers of fabric were wet at the die entrance with excess volatiles driven off as shown in Figure 4-32. The die length had to be considerably shorter for epoxies due to their tendency to stick and cure in the die. A four-inch-long section was cut from the original 30-inch die and this section was used for the epoxy pultrusion. A drawing of the shorter die, BHTI 599-603-001 DTC-3-1, is shown in Appendix E. The die temperature was held at 150°F throughout the run to prevent curing.

The resultant product was far from satisfactory. The epoxy started sticking in the die and fabric fragments sheared off and magnified the problems as shown in Figure 4-33. This precipitated frequent shutdowns for die cleanup. The matrix did not sufficiently wet out the fabric or roving resulting in a fragile, nonuniform cross section (Figure 4-34), which appeared stiff and low in resin content. The lack of impregnation was due to a combination of the high solids content of the bath and the heated die driving off residual solvent.

4.3.3.3 Prepreg Epoxy Pultrusion. The next step was to attempt to pultrude E773 prepreg for evaluation. Two hundred pounds of E773 prepreg roving, 60 end count, were purchased from U.S.

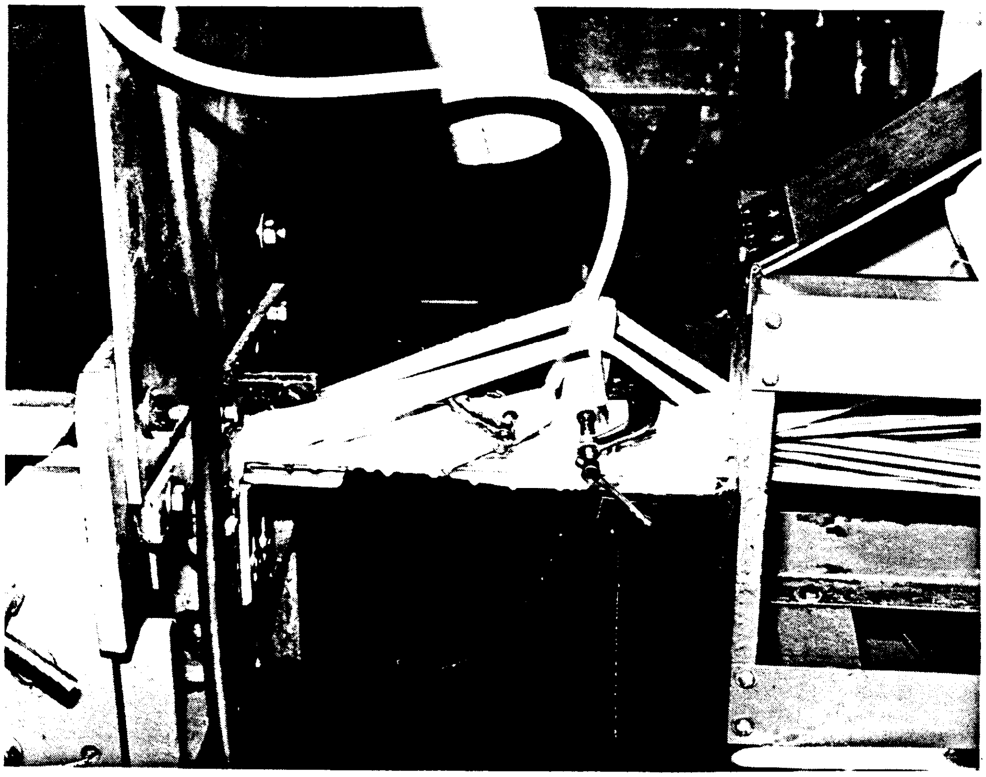


Figure 4-32. Material guidance prior to pultrusion die.

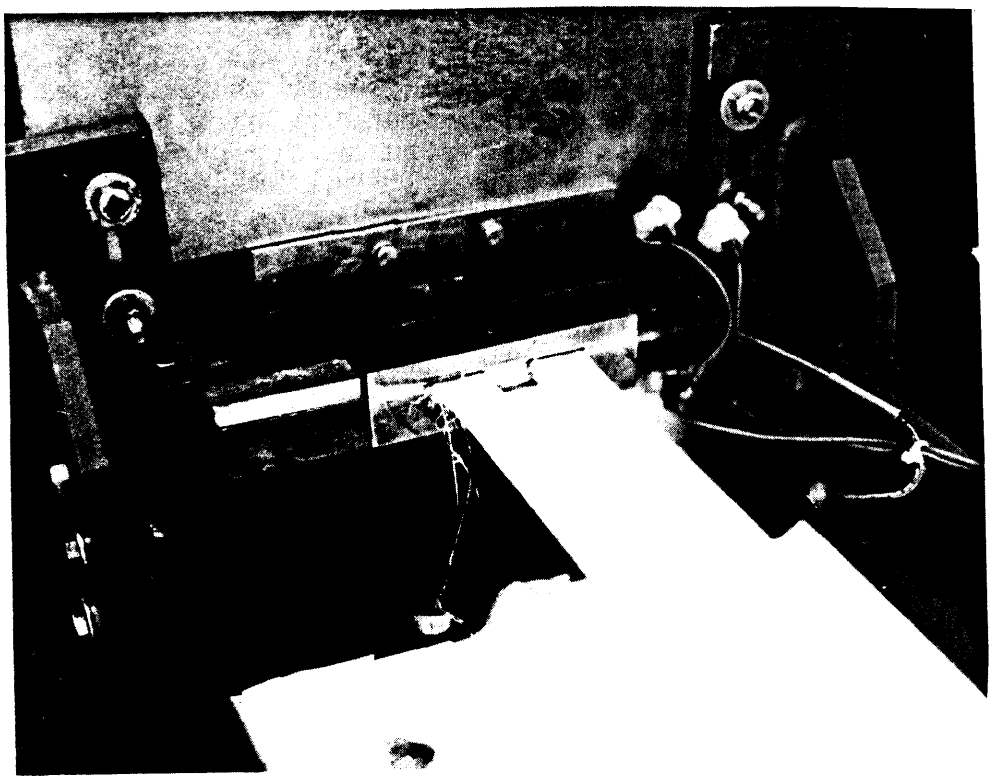


Figure 4-33. Pultrusion die with fabric fragments and cured epoxy.

Figure 4-34. Nonuniform cross section caused by insufficient wetting.

Polymeric. The basic setup of the previous pultrusion trials was used with the exception of the wet bath and fabric. Prepreg roving was pultruded through a 150°F die as shown in Figure 4-35 producing a nice looking, handleable preform without good transverse strength. An additional trial adding wetted fabric produced a preform with the fabric peeling off in handling and due to lack of control in fabric application, was poorly covered.

At this point it was decided to investigate the possibility of adding the fabric during the postforming step. A pultrusion trial was attempted using dacron to replace the fiberglass fabric during pultrusion to produce a preform that would be undersized when the dacron was removed before postforming. The pultrusion results were marginal and the preform did perform well in a postforming test with application of the fabric at that time. However, the excess time required to apply the fabric could have been used for a complete hand layup and the concept was discarded.

Changes in the die configuration, fabric folding and the fiberglass fabric/resin form provided the breakthrough. Another four-inch die was machined and plated 0.010 inch undersize and a third four-inch die was machined and plated 0.005 inch oversize. This provided a three die system with the primary die undersized to form and debulk the prepreg rovings, the secondary die net size (previously used) for fabric application and a oversized tertiary die for cooling of the preform. A new fabric folding shoe (Figure 4-36), designed by Goldsworthy, enabled the fabric to be wrapped around the prepreg roving form in two pieces instead of four making it much easier to control. At the same time, the fabric/resin composition was changed to Hexcel's F185 adhesive prepreg which is a 50 percent resin content 7781 weave E-glass material curing in 90 minutes at 265°F. This material also has been used at BHTI and is compatible with E773. The fabric and rovings entering the folding tool and die are shown in Figure 4-37, the fabric feeding into the open secondary and tertiary dies in Figure 4-38 and the final preform exiting from the secondary die in Figure 4-39. The materials cooled sufficiently upon exiting the secondary die to stabilize without use of the tertiary die. The preform was exactly as required as shown with the puller in Figure 4-40. The dies were controlled at 150°F yielding a feed rate that was increased from 3 to 10 inches per minute as the trial continued with loading at 4,000 pounds. The cross section was uniform and stable while the fabric and rovings held together during handling but were malleable enough for slight changes at room temperature. The final door track pultrusion operation is shown in Figure 4-41.

Due to time constraints, and the faith in the reinforcement/ resin system, it was decided to move directly into the next

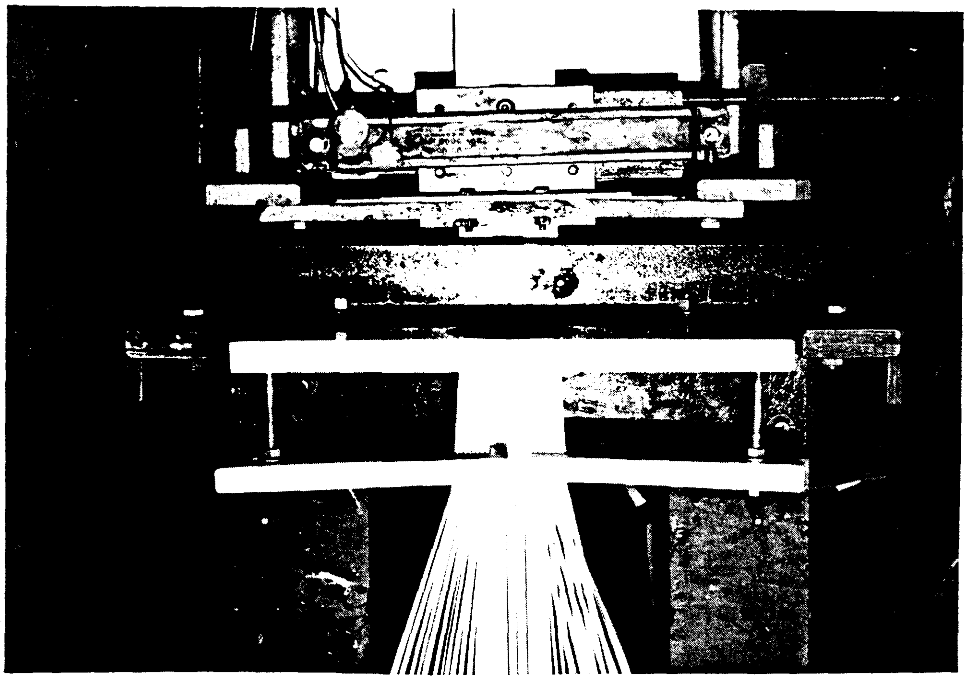


Figure 4-35. Top view of roving entering die and exiting as a pultruded preform.

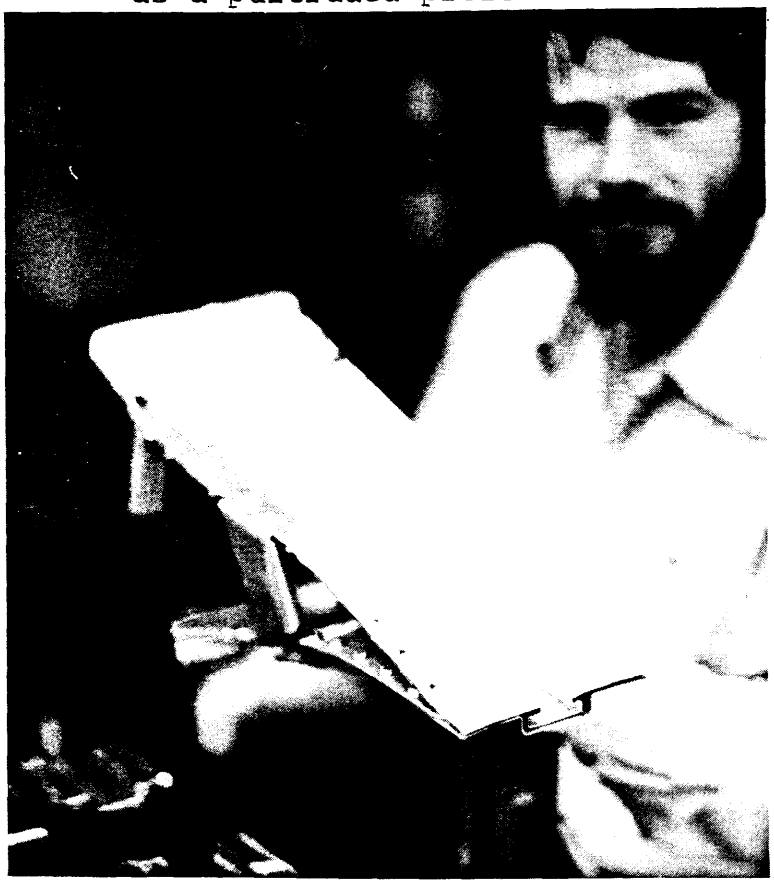


Figure 4-36. Pultrusion fabric folding shoe.

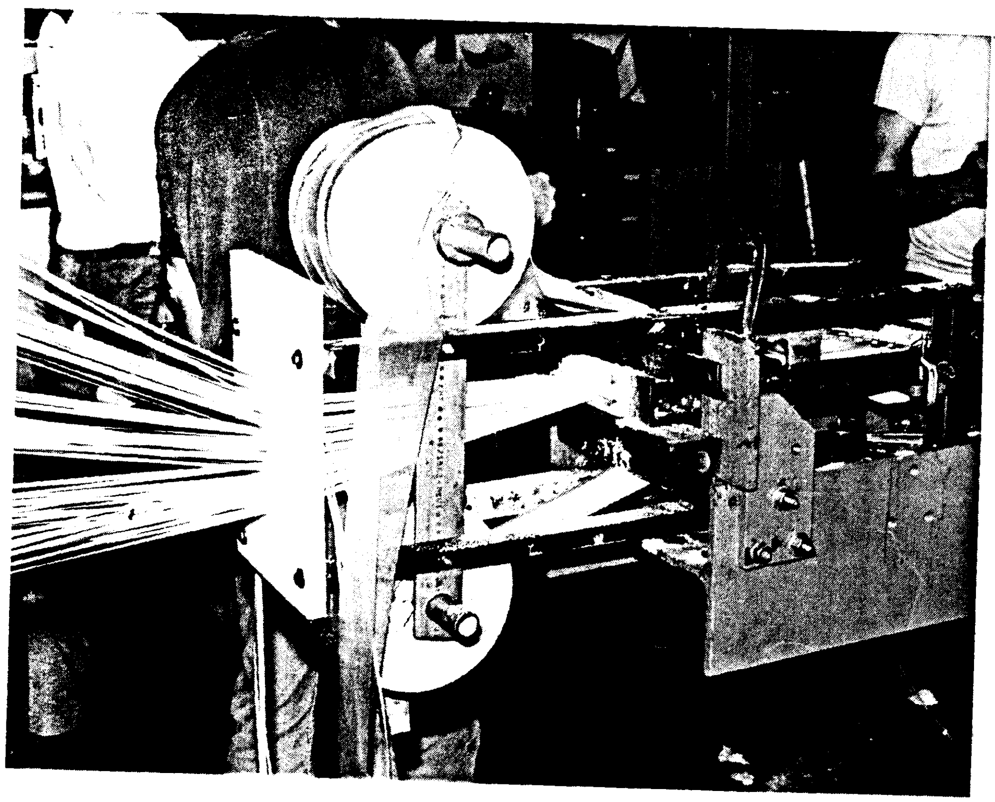


Figure 4-37. Pultrusion material supply and guidance.

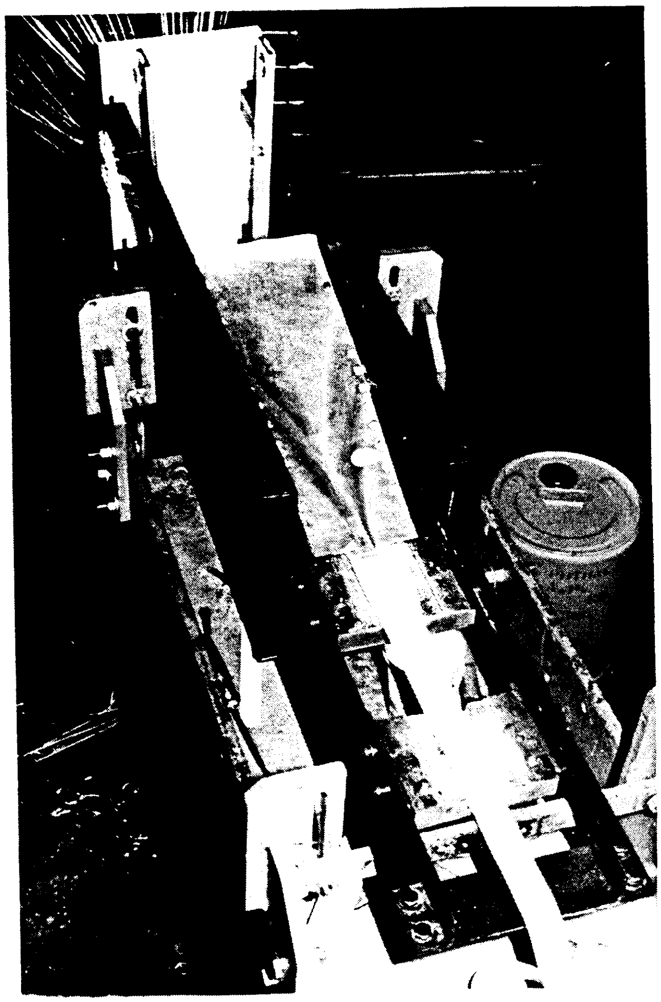


Figure 4-38. Pultrusion overview of open die halves and fabric fold tooling.

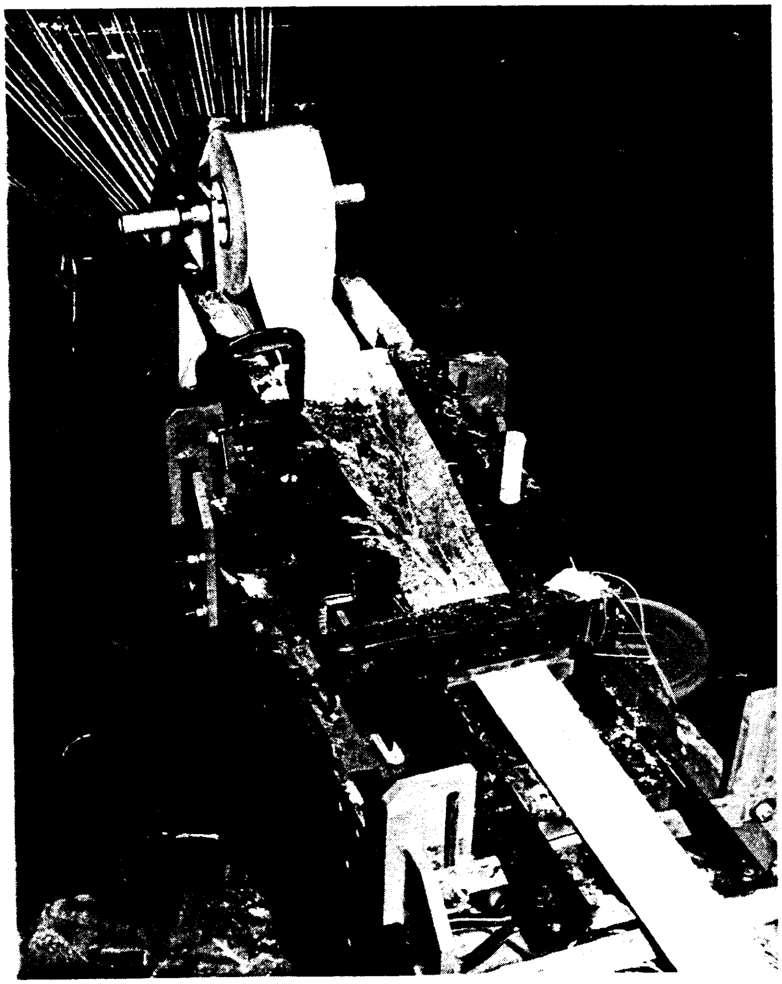


Figure 4-39. Preform exiting from two-stage pultrusion dies.

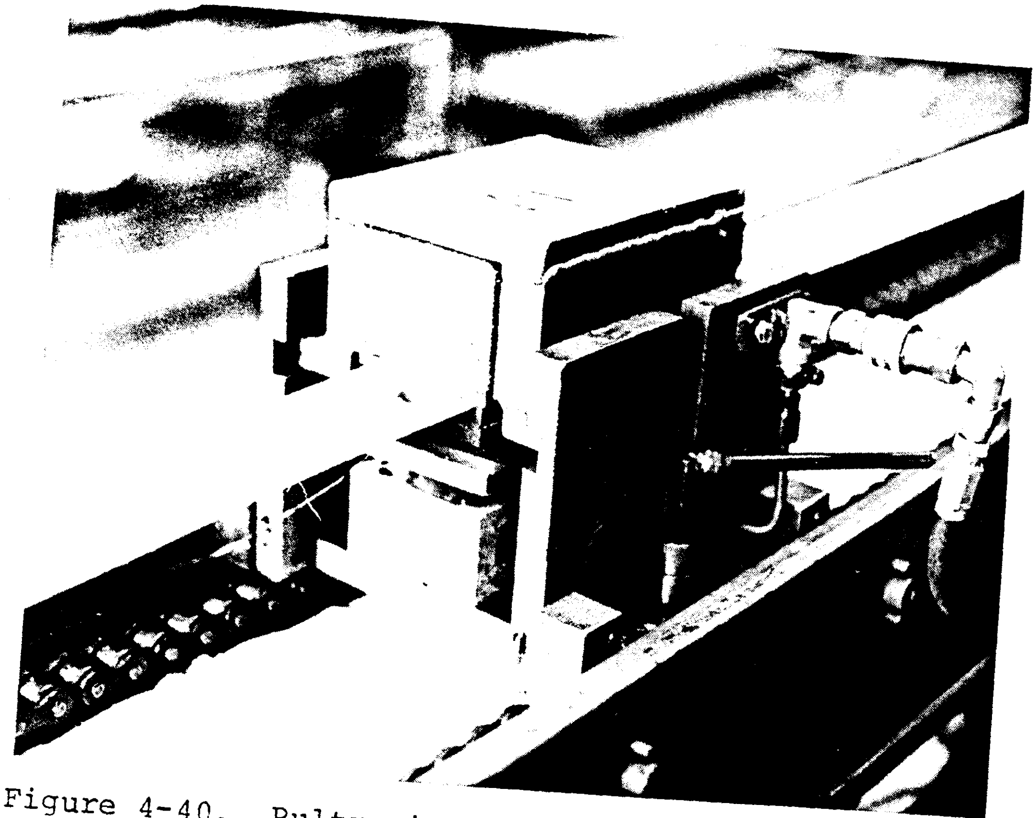


Figure 4-40. Pultrusion machine puller clamped on pultruded preform.

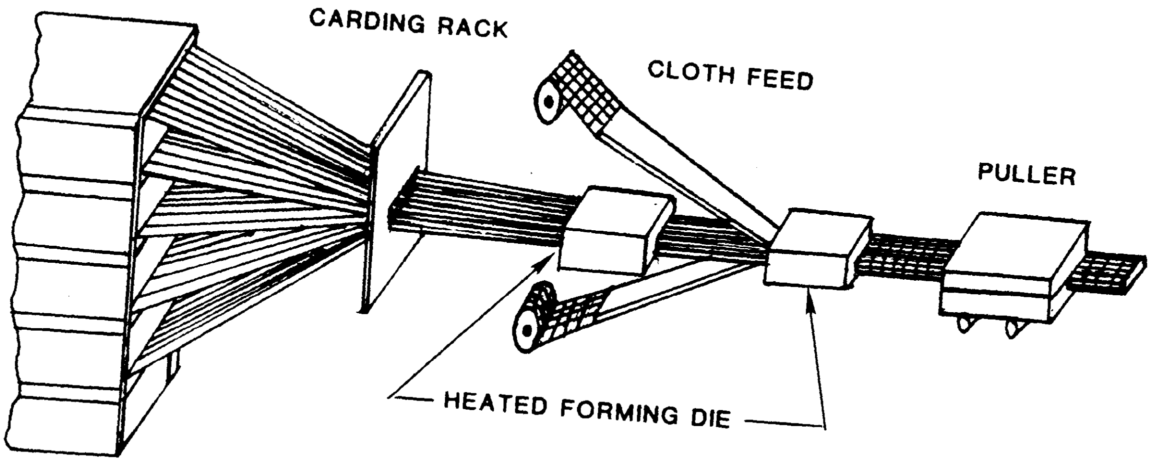


Figure 4-41. Door track pultrusion operation.

task and pultrude and postform complete door tracks from which test specimens for paragraph 4.3 would be extracted and tested. At the same time as the test samples were being cured and postformed, the postforming parameters were determined.

4.4 TASK IV - FABRICATION OF DOOR TRACKS

This task was the culmination of all the design, testing, and effort expended in the previous three tasks. A minimum of 10 pultruded and postformed door tracks were to be produced with tests performed to verify design performance. Manufacturing and economic comparisons were made between the postformed, hand layup and present aluminum door track including a cost analysis of producing 10, 100 and 1,000 production parts.

4.4.1 Pultrusion of Door Track Blanks

The test specimen and door track blank preforms were pultruded in accordance with the parameters determined in 4.3.3.3. The pultrusion run was quite successful resulting in 216 feet of usable preforms out of 300 feet pultruded. The loss was due to the normal startup problems and would decrease dramatically as a percentage of the usable material if the run was extended. Although the cross section was symmetrical, close examination indicated an average wall thickness of 0.065 inch which was due to poor debulking in the die. Consequently, 61 rovings were counted entering the die rather than 90 as calculated (see Figure 4-42). Minor die changes would permit better debulking. The preforms were cut into 8-foot lengths, stabilized with wood inserts and shipped to BHTI by air in dry ice for storage at -30^{o}F. Experience with the matrix materials has demonstrated a shelf life of at least 30 days at 75^{o}F.

4.4.2 Postforming Parameters

The postforming processing parameters were determined by forming full door track sections which were cut into test specimens. This method saved time and provided test specimens for Section 4.3 that were representative of the finished track.

The first step in the postforming process was to insert the rubber bun into the preform, both shown in Figure 4-43. This was easily performed by raising the inner flange of the preform and then tucking it down into the recessed edge of the bun after insertion. The next step was to fit the preform and bun into the female postforming tool as in Figure 4-44. After performing this step which posed no problems, Teflon coated fiberglass was placed over the preform as in Figure 4-45 and the 0.125-inch-thick aluminum caul plate taped in place, Figure 4-46. A cross section view of the postforming tool with the preform is shown in Figure 4-47. The tool, excluding the sup-

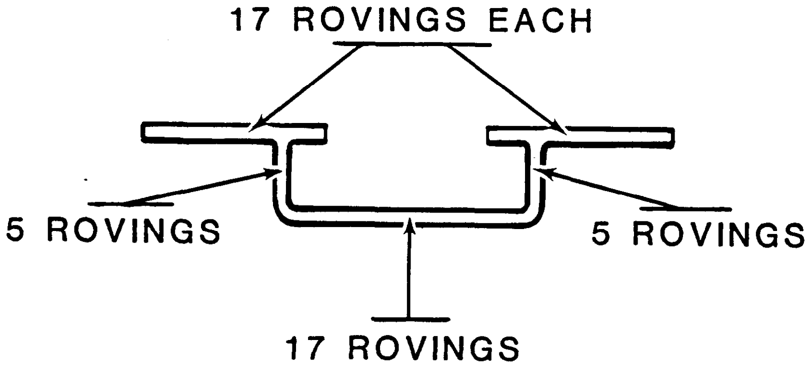


Figure 4-42. Door track roving placement.

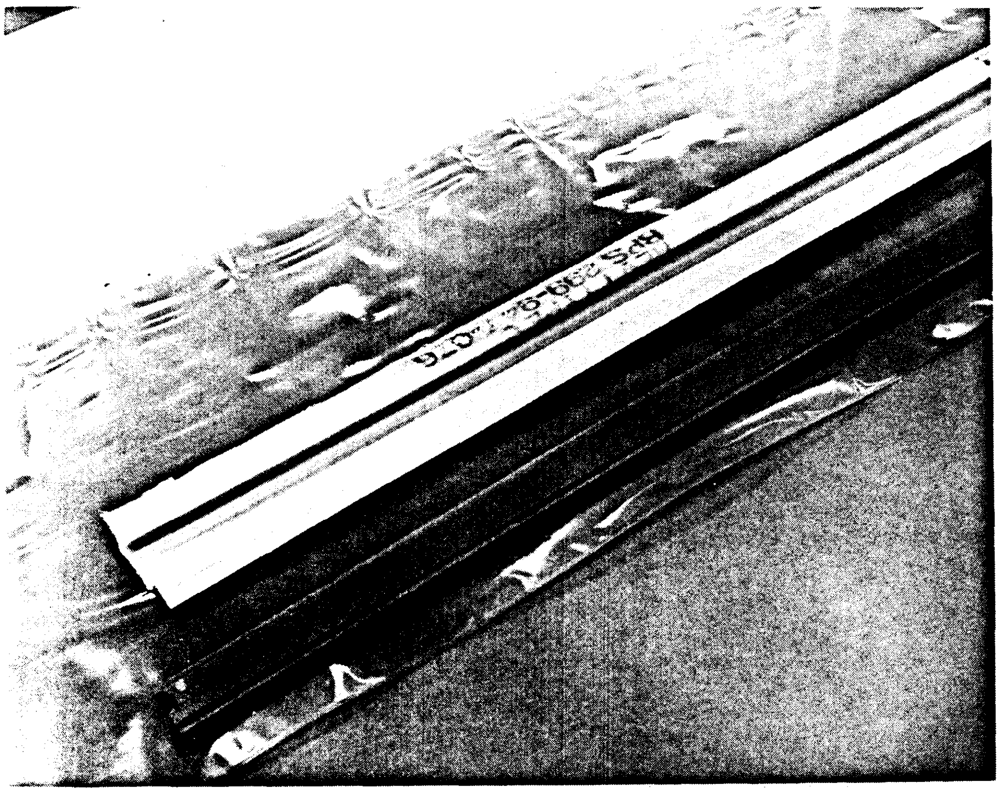


Figure 4-43. Pultruded preform and silicone rubber bun.

Figure 4-44. Fitting pultruded preform and rubber bun into female postforming tool.

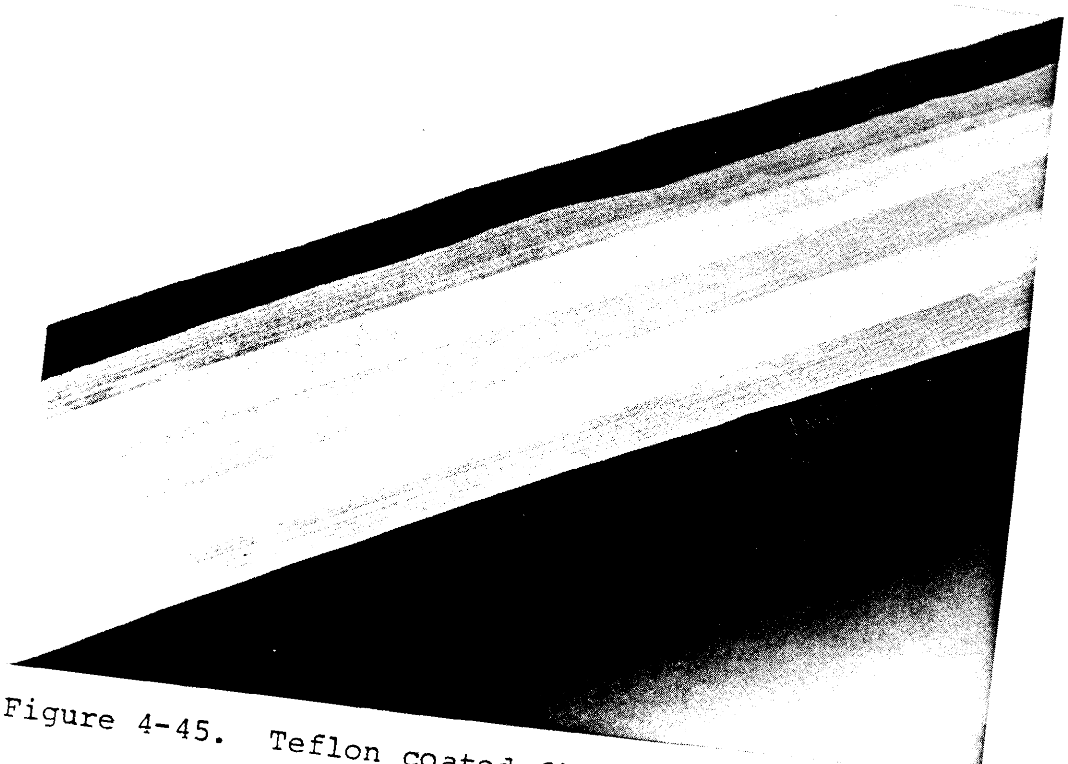


Figure 4-45. Teflon coated fiberglass placed over preform.

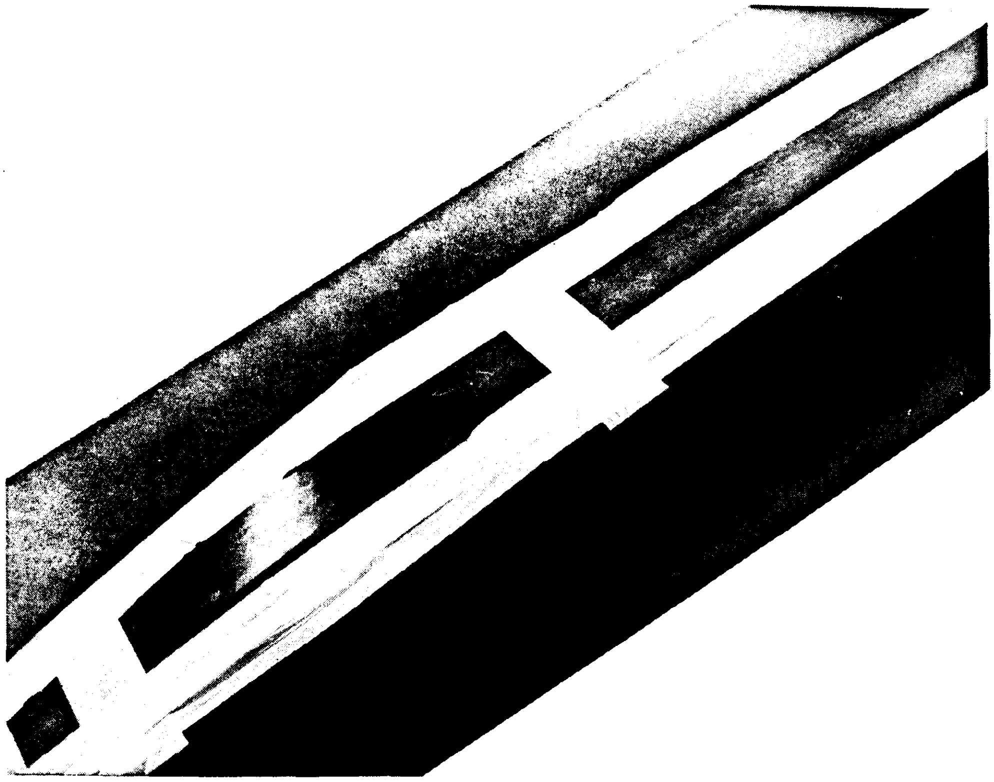


Figure 4-46. Aluminum caul plate taped in place.

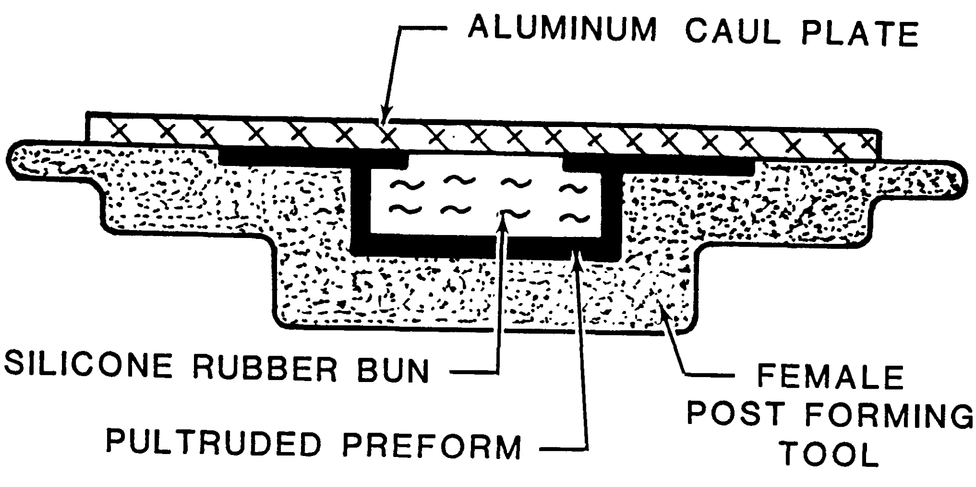


Figure 4-47. Cross section of part and postforming tool.

port, was then vacuum bagged and placed in a 4- x 9-foot autoclave with production parts and cured for 75 minutes between 240° and 280°F at 50 psi according to the cure cycle in Figure 4-48.

After cooling to 120°F, the part was debagged and the caul plate removed, Figure 4-49. The part was detached from the female tool (Figure 4-50) with little difficulty considering the curve and twist formed into the door track. Figure 4-51 shows the rubber bun separated from the door track. The bun was dislodged by pulling on one end until the stretch was taken up at which point it slid out easily. The formed track indicates a minimum of flash making it easy to trim. Six tracks were formed by this method for destructive test specimens.

4.4.3 Test Specimen Fabrication and Testing

The destructive test specimens were excised from the crown at the hat section of the door track as shown in Figure 4-52. It would have been appropriate to use flange samples for supplementary testing except that the flanges were too narrow for sample preparation.

The tensile and flexural specimens were prepared according to Figure 4-9, Section 4.1.2, and tested per Federal Test Method 1011, Standard 406 (Tensile Properties) and Method 1031 (Flexural Properties). Tests were conducted on BHTI's Tinius Olsen UEH Test Machine with a 30,000 pound capacity, Figure 4-53. A typical tensile testing setup is shown in Figure 4-54 and a flexural test fixture is shown in Figure 4-55.

Test results for the specimens are shown in Table 4-2. The results are the mean values of 5 test specimens (reported in Appendix F). Again, as in 4.1.2, BHTI material specifications were used solely on a comparative basis. Good consistency was shown in all tests with the tensile values far exceeding the 299-947-076 spec (applicable to the F-185 E-glass fabric prepreg) and falling far short of the 299-947-134 (applicable to the E773 S2-glass prepreg roving). This is understandable when it is taken into consideration that the outer wrap fabric is E-glass and consists of 30 percent of the specimen volume. Therefore the E-glass ruptures first as shown in Figure 4-56 putting the load on the unidirectional roving which finally gives way.

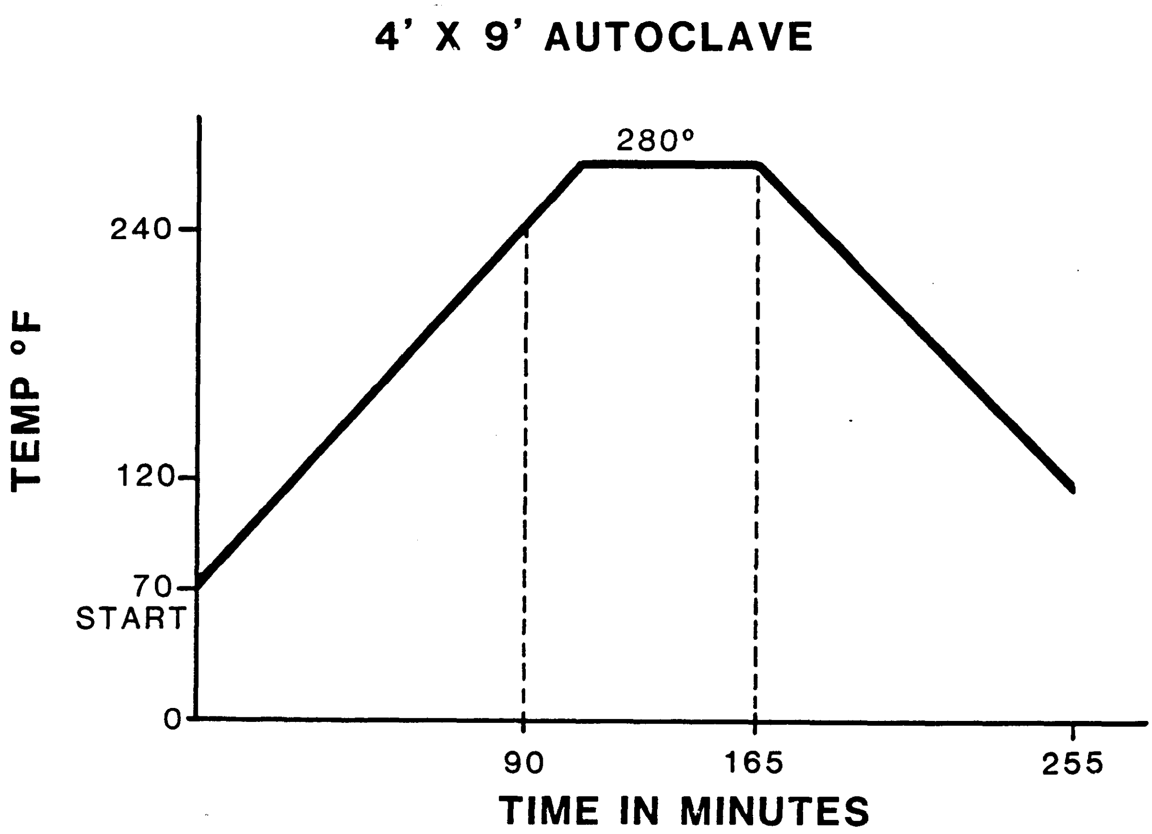


Figure 4-48. Postforming cure cycle.

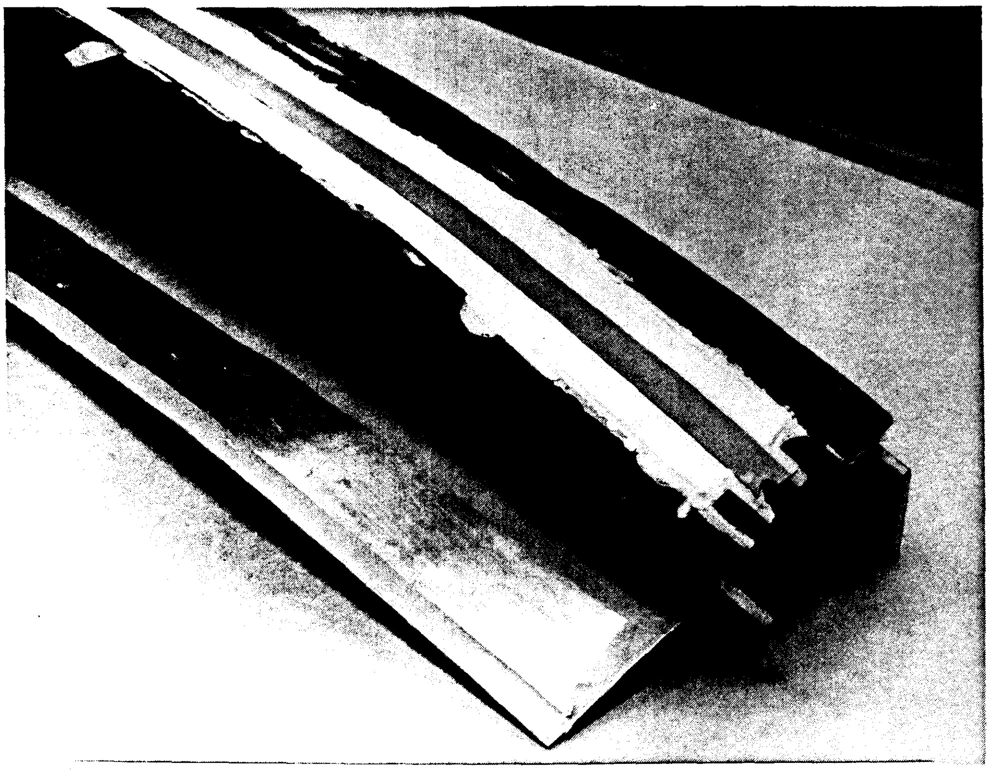


Figure 4-49. Debagged part with caul plate.

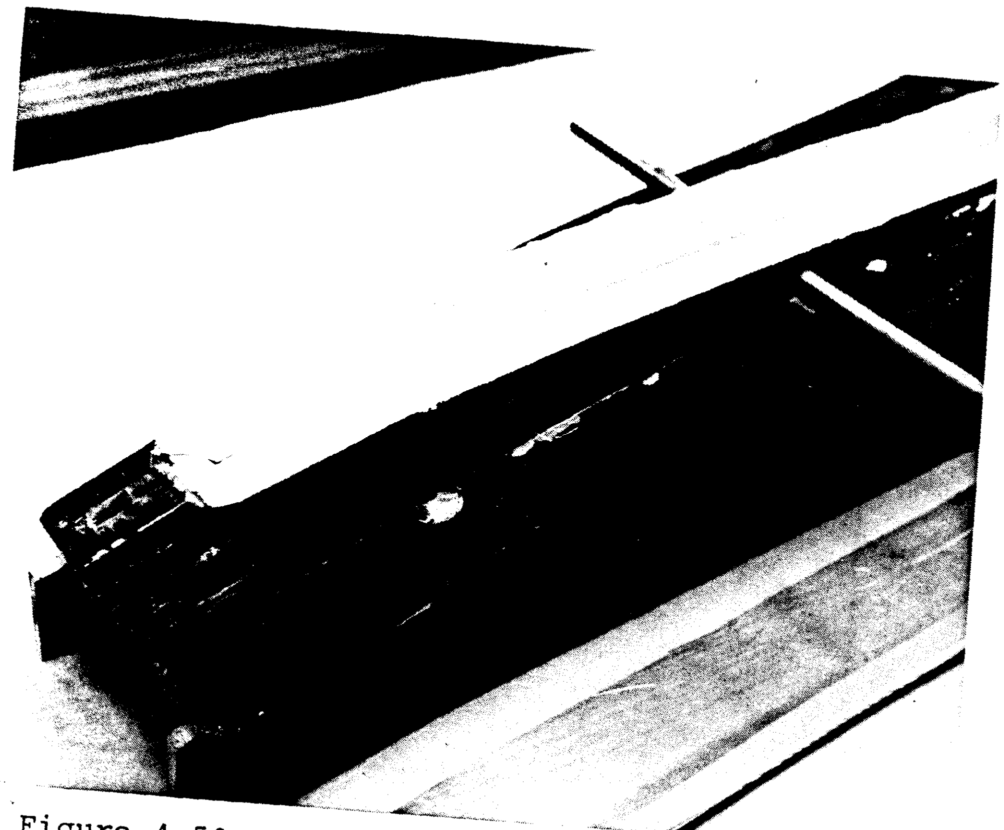


Figure 4-50. Removal of cured part from tool.

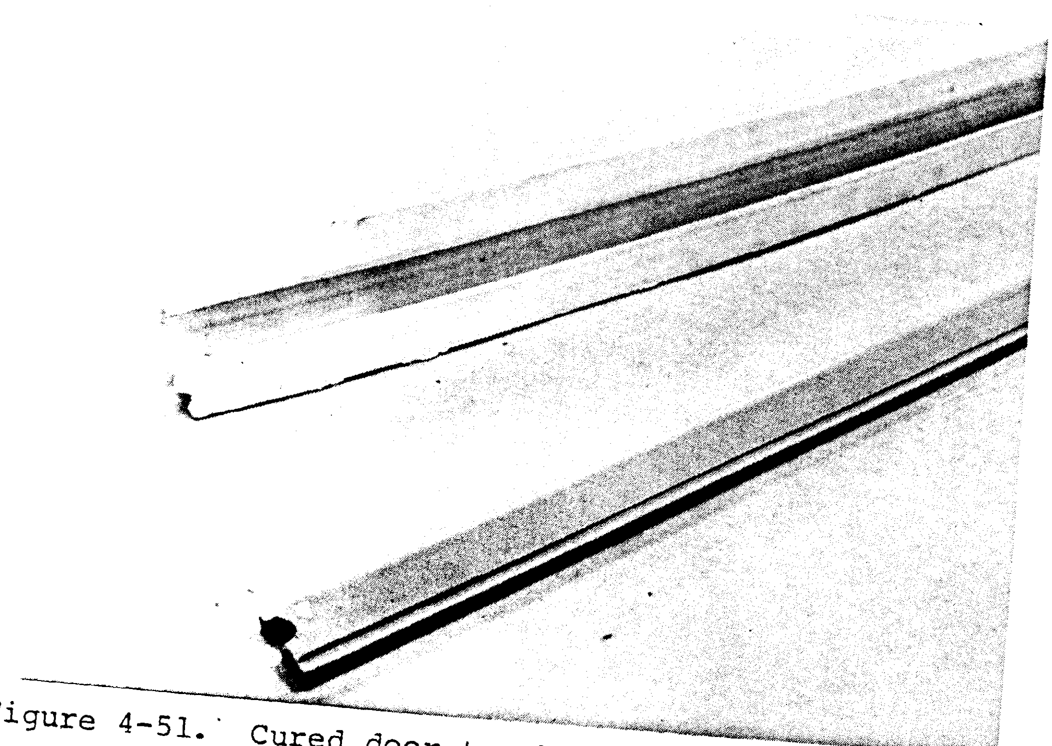


Figure 4-51. Cured door track with rubber bun removed.

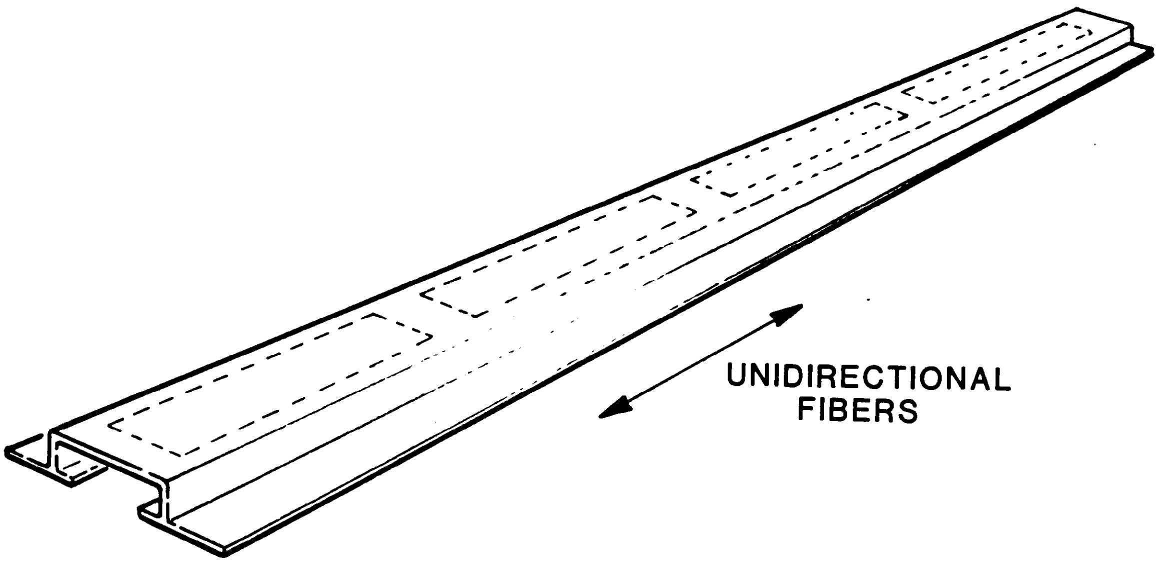


Figure 4-52. Destructive test specimen removal area.

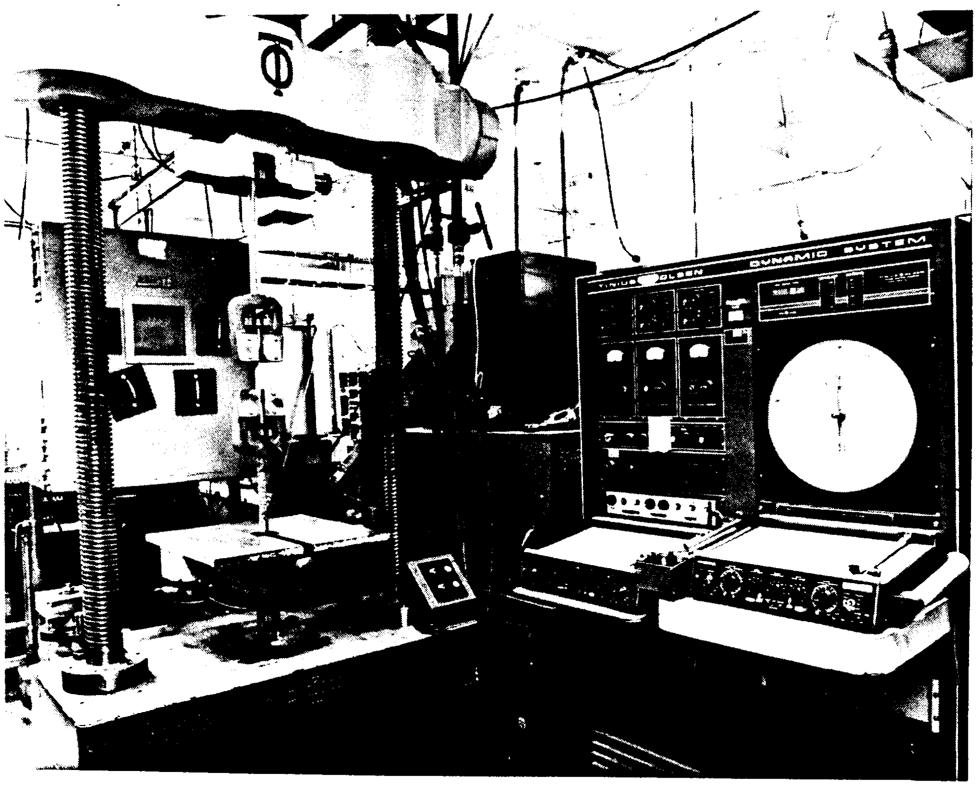


Figure 4-53. Tinius Olsen UEH test machine.

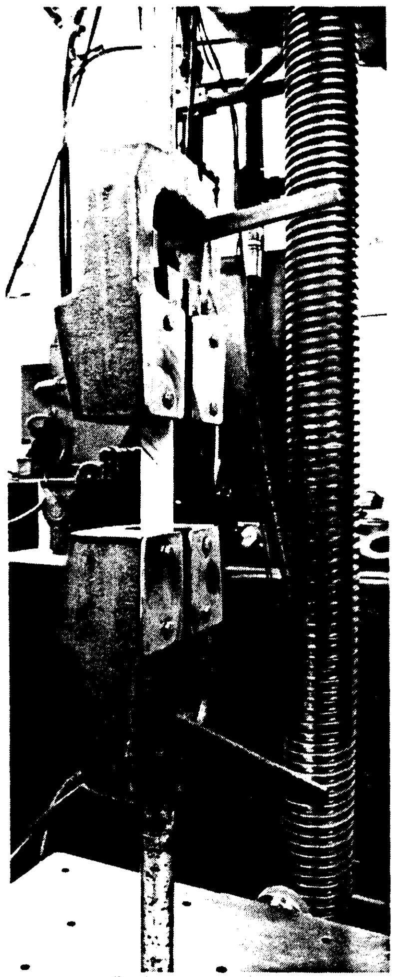


Figure 4-54. Typical tensile testing setup.

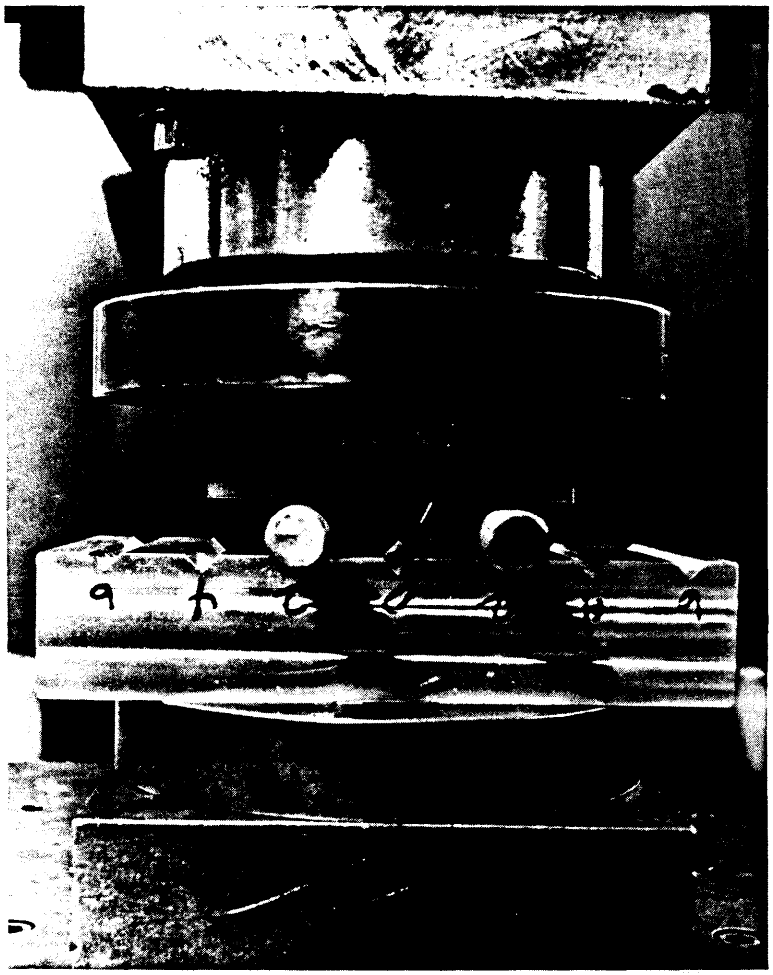


Figure 4-55. Flexural test fixture and specimen.

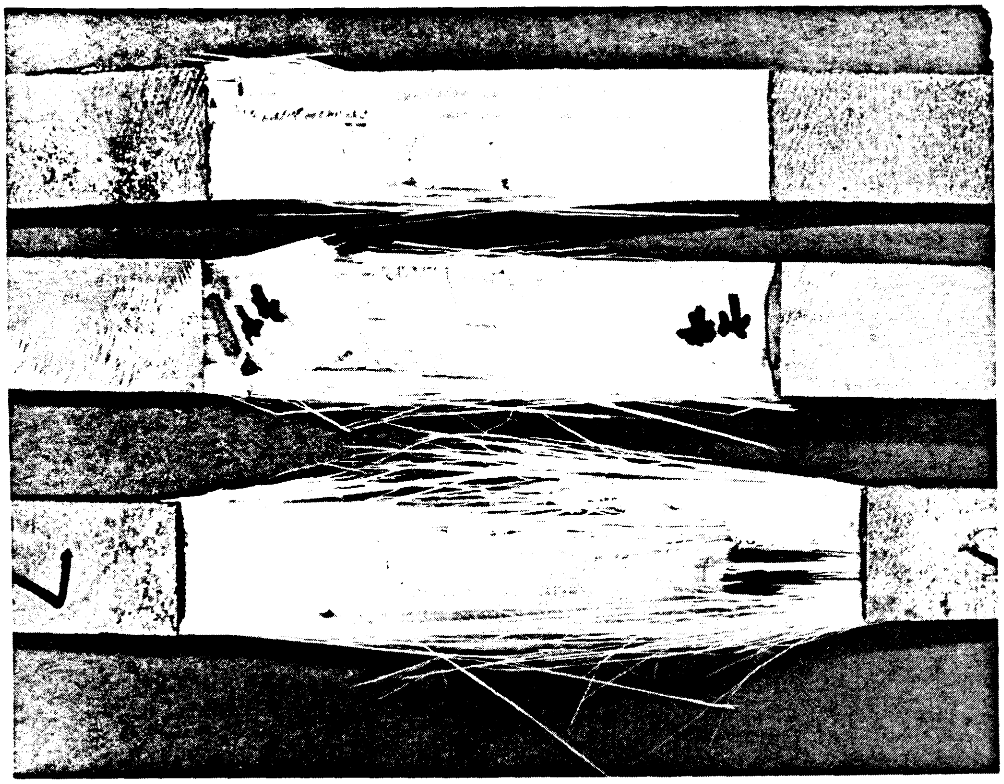


Figure 4-56. Failed test specimens showing primary fabric failure.

TABLE 4-2. TEST SPECIMEN RESULTS

Test Condition	Tensile (psi)		Flexural (psi)		Resin Content (%)
	Mean	Std. Dev.	Mean	Std. Dev.	
75°F Control	115,224	20,661	106,233	9,580	32.7
75°F @ 2 Day H_2O Soak @ 125°F	130,868	23,907	103,493	7,333	-
75°F @ 21 Days @ 125°F and 95% R.H.	97,127	11,228	101,349	10,140	-
75°F - Bell Spec. 299-947-076	47,000 Min		None		50
75°F - Bell Spec. 299-947-134	185,000 Min		None		33

4.4.4 Postform, Cure and Trim

Ten demonstration door tracks were postformed and cured according to the parameters in 4.4.2. All operations went smoothly with the postforming and trimming becoming more efficient with each part produced as will be shown in the section on Manufacturing Methods.

Trimming of the parts was aided with an existing template, Figure 4-57, used for determining the engineering lines on the present aluminum door track. The aluminum door track used for a pattern contained a location hole. This location hole was transferred to the postforming tool and marked on the postformed parts. The location point was then matched up with the trim template, as shown in the right side of Figure 4-58, and became the basis for all trim lines. A mylar (Figure 4-59) was used to determine the cutout area for door removal. All cutting of the tracks was accomplished with a diamond saw, Figure 4-60, and final trimming with conventional routers, Figure 4-61. Figure 4-62 shows one of the composite cargo door tracks along with the present aluminum part. Eleven trimmed and finished composite door tracks are shown in Figure 4-63 with a closeup of the trimmed ends in Figure 4-64 before shipment of eight of the door tracks to the U.S. Army.

Figure 4-57. Door track trim template.

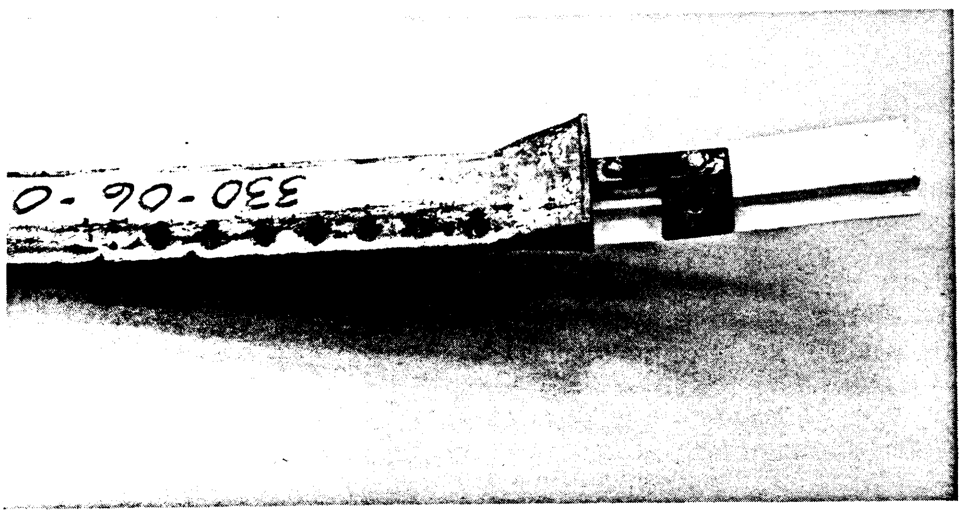


Figure 4-58. Location point matched to trim template.

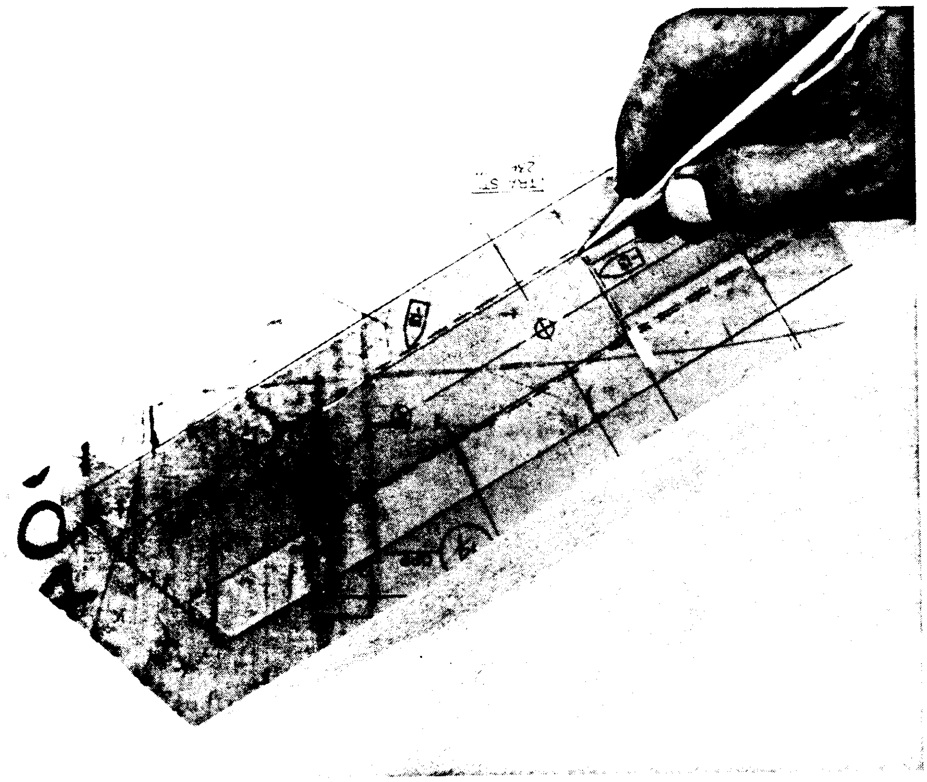


Figure 4-59. Mylar used to determine cut-out area for door removal.

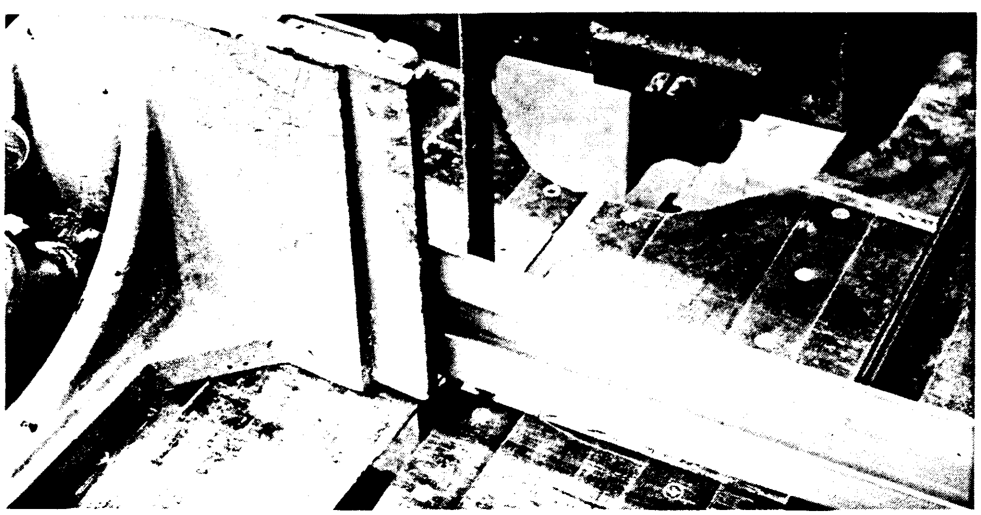


Figure 4-60. Door track cutting with diamond saw.

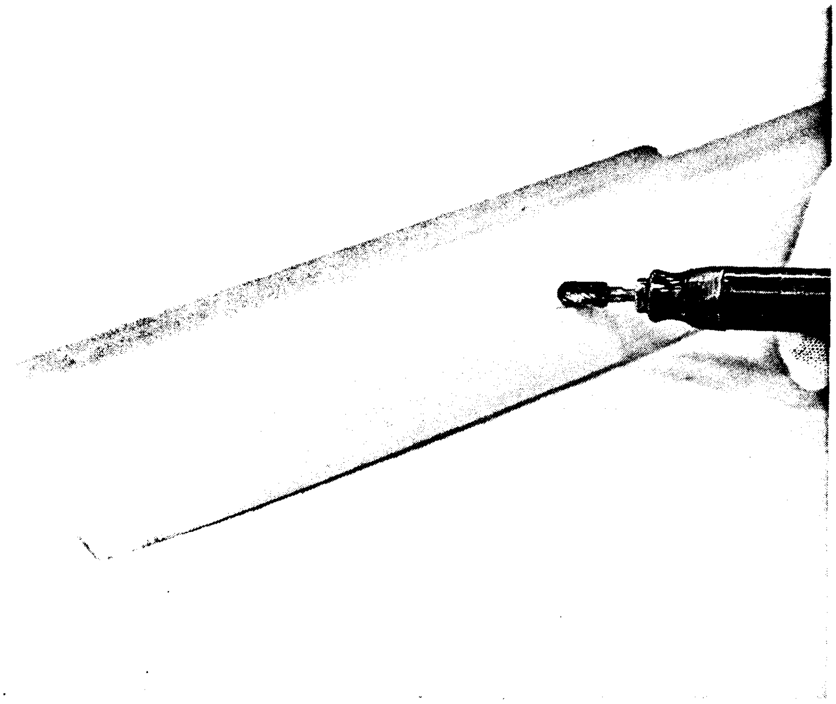


Figure 4-61. Final trim with conventional router.

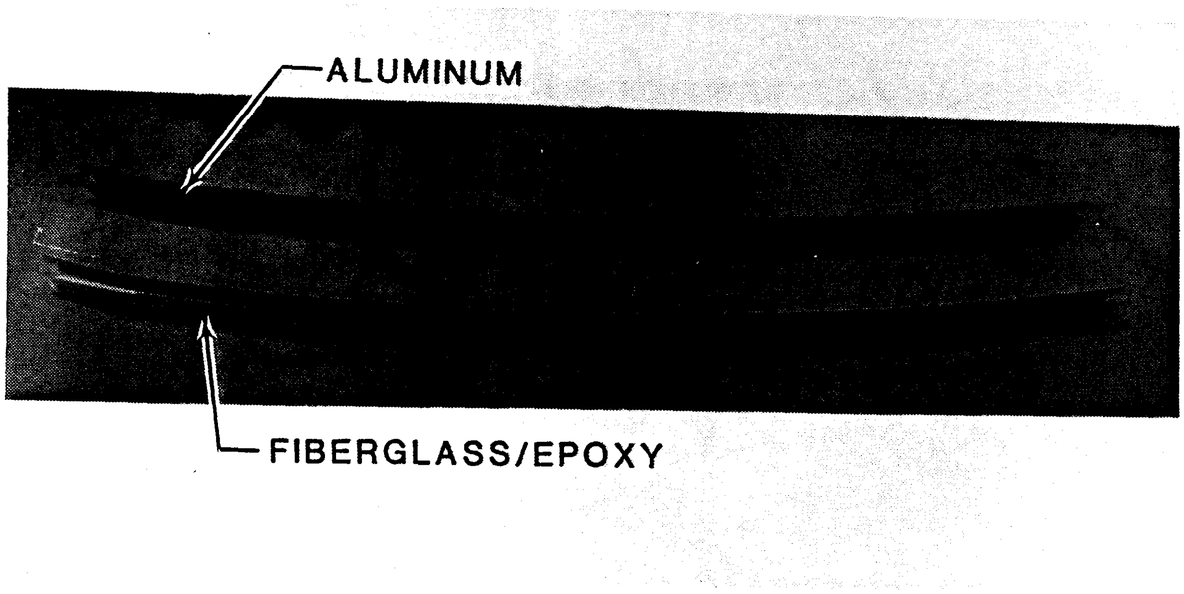


Figure 4-62. Aluminum and postformed cargo door tracks.

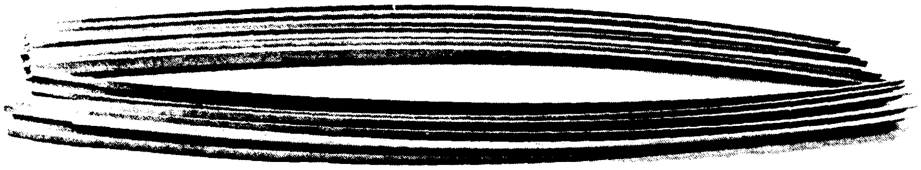


Figure 4-63. Eleven trimmed and finished postformed door tracks.

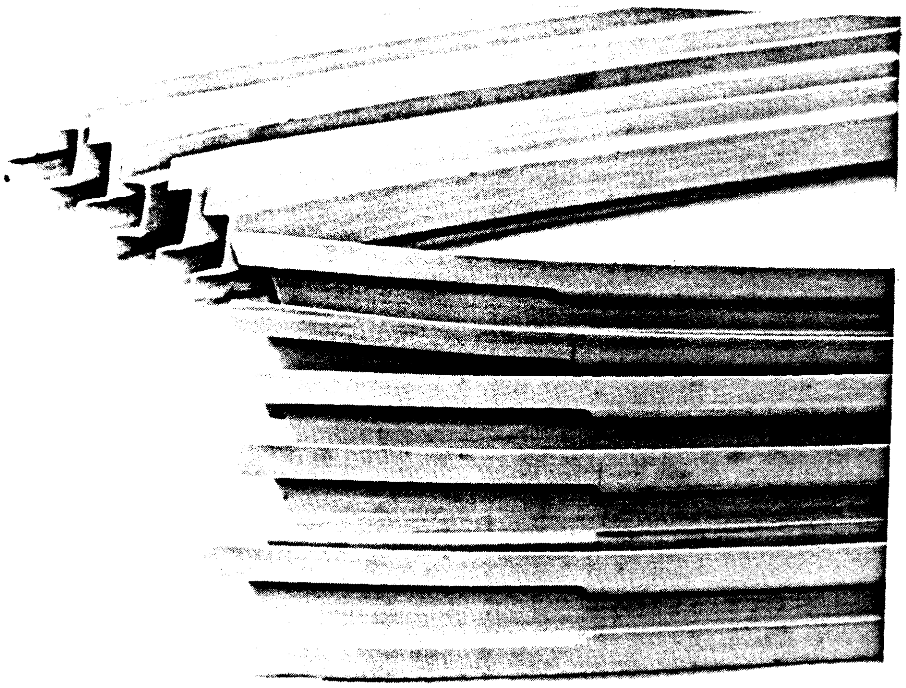


Figure 4-64. Closeup of the trimmed door tracks.

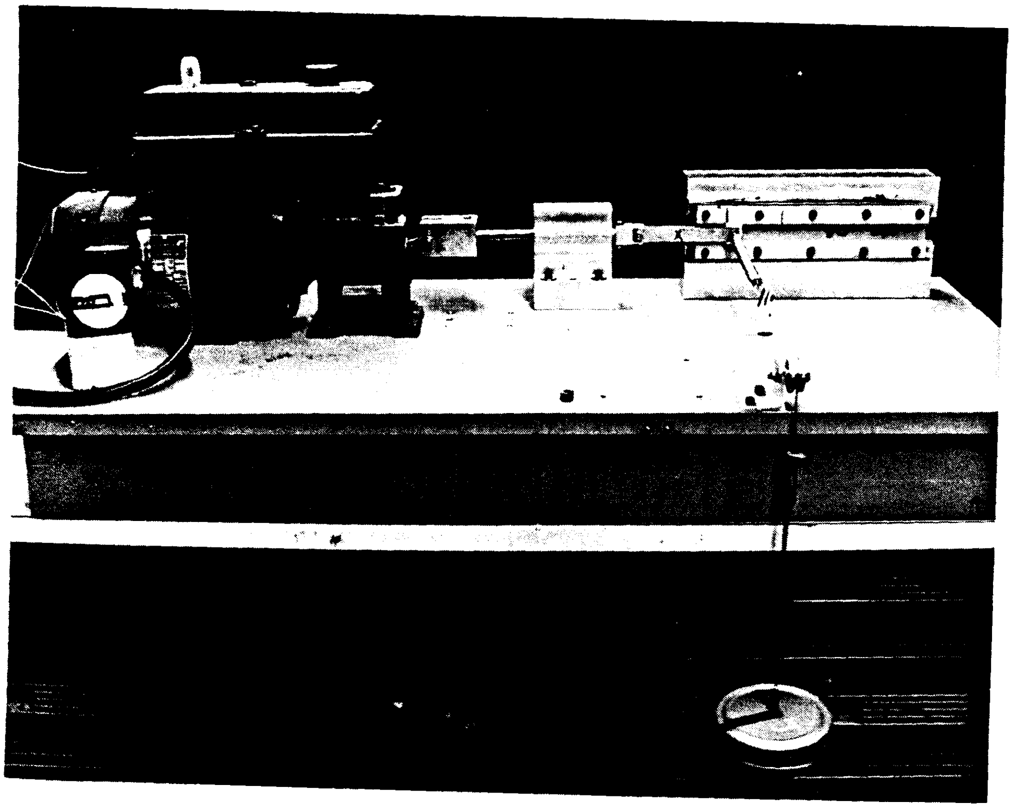


Figure 4-67. Wear test fixture and specimen.

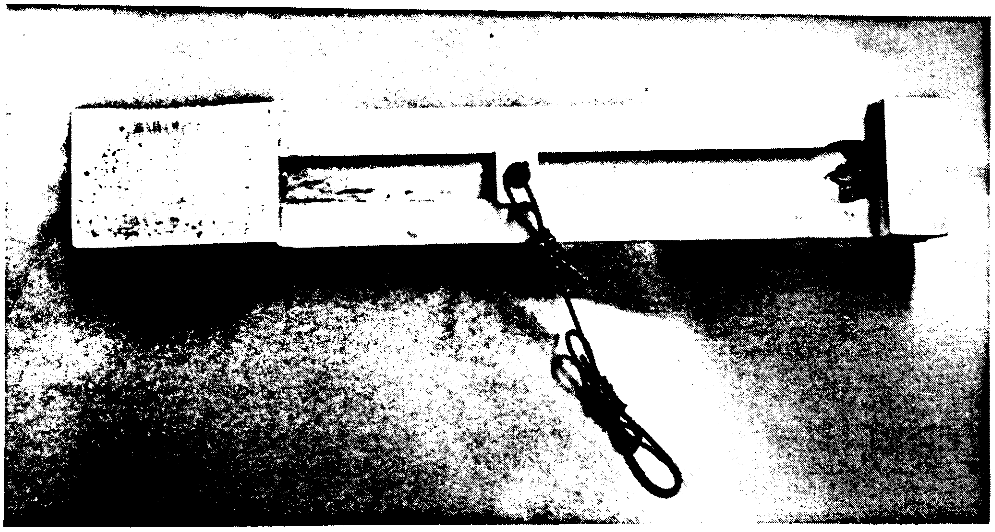


Figure 4-65. Static test specimen with pennlon slider.

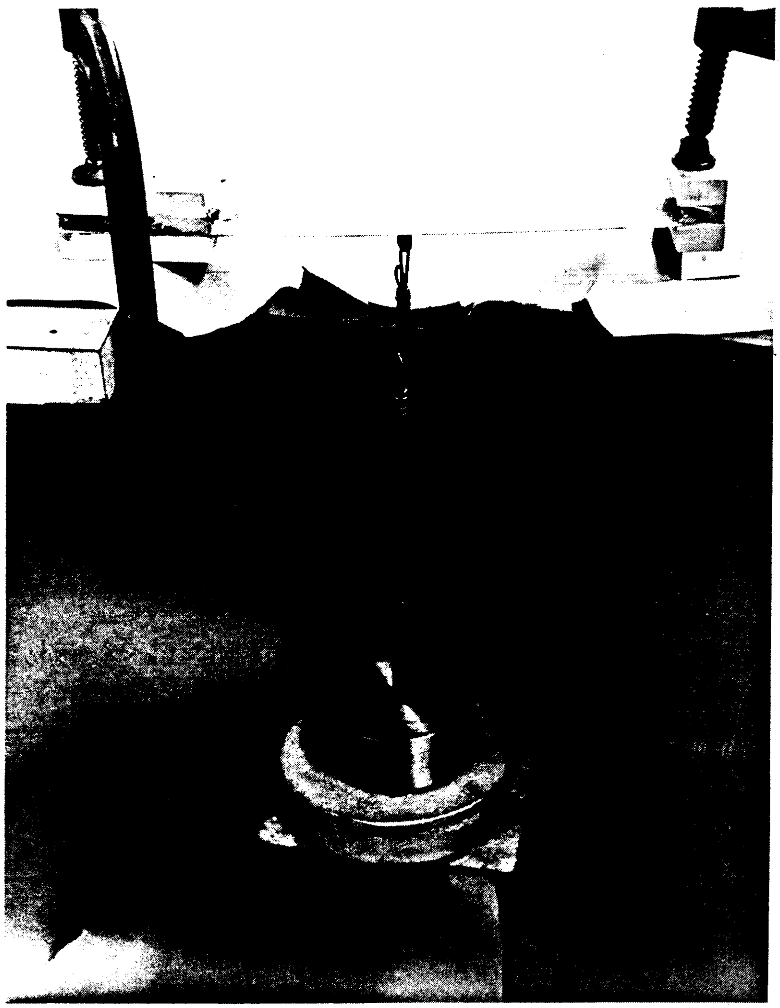


Figure 4-66. Static load testing of composite door track.

The prototype door tracks required 266 fabrication hours for 16 units, an average of 16.5 man-hours per unit. The comparative learning curves are shown in Figure 4-68 with the prototype parts fitting a 76 percent slope as the fabrication time was reduced from 36 to 11.5 man-hours per part over 16 parts. Based on the prototype experience, production for 10 parts should commence at 10.5 man-hours per part and drop to 6 and 3.5 man-hours at 100 and 1,000 parts respectively on an 85 percent learning curve. Part of this change is attributed to the ability to pultrude at 24 inches per minute, lower scrappage, and more efficient postforming tooling at 100 parts.

The comparisons between pultrusion, hand layup and the aluminum door track are shown in Figure 4-69. Hand layup shows a slight advantage over pultrusion through 7 parts but the learning curve slope changes at 10 parts from 81 to 85 percent. Beyond 10 parts, the pultrusion portion of the postformed door track declines quite significantly to 0.2 man-hour at 1,000 parts. There is no corresponding savings in any of the hand layup operations so that the postformed part will always have a lower labor content in production volumes.

The present aluminum door track is purchased as a 2024-T4 aluminum extrusion and is then put through a series of 22 steps. This includes cutting, stretch forming, milling, hardness checking, hard anodizing, priming, and a number of degreasing and protective wrap operations. More than 20,000 aluminum door tracks have been fabricated bringing down the labor content to a very low rate. The present labor standards had to be adjusted to determine the labor costs at 1,000 parts and less. Due to the metal working experience involved and rapid machine setups, a 90 percent learning curve was considered applicable.

At 1,000 parts, the raw material costs for postforming and aluminum are extremely close at $1.42 per foot and $1.49 per foot respectively as shown in Figure 4-70. This is based on a prepreg cost of $5.00 per pound. Hand layup materials would cost $5.55 per foot as significant savings could not be accomplished by increased volume.

The weight savings are significant with the composite tracks weighing 1.5 pounds each versus 2.2 pounds for aluminum. This weight savings totals 1.4 pounds per ship for 2 tracks. At an estimated value of $100 per pound, the ship savings value is $140.

The labor costs for the composite tracks cannot compete in fabrication time with the standards set for the aluminum track if the realization is 100 percent. However, a new part could conceivably have different economics if extensive machining or other operations were involved, or if weight savings was a primary factor.

4.4.6 Manufacturing Methods and Cost Analysis

Labor operations at BHTI are broken down in Table 4-4 into process and direct labor. This table is shown only for comparison as some of the operations would change categories for other companies.

TABLE 4-4. LABOR OPERATIONS

Process Labor	Direct Labor
• Bag for autoclave	• Rack materials
• Autoclave cure	• Pultrusion
• Debag	• Gather materials
• Saw	• Cut templates
• Degrease	• Trim details
• Chemical treat metal details	• Layup materials
	• Prepare molds
• Wrap, package details	• Final trim
• Inspection	• Stretch form aluminum
	• Hand rout and drill
	• Mill
	• Bench work

For consistency and future reference all direct and indirect labor and purchased services such as pultruded stock, were converted to man-hours. Raw materials were left in 1981 dollars as conversion to man-hours would depend upon the individual supplier's rates.

Tooling costs were not included in the final analysis as the aluminum track tooling is of a minimal cost and the postforming tooling can be used for fabricating either the postformed or hand layed up tracks. Pultrusion tooling required 390 man-hours and postform tooling 48 man-hours with a total raw material cost of $530. No new pultrusion tooling would be required through 1,000 parts. At 100 parts, an aluminum double cavity tool would be fabricated at a cost of $3,800 and 150 man-hours to postform right and left tracks simultaneously. This tool could be used for either composite fabrication method and would be press compatible, speeding up cure cycles and eliminating all autoclave operations.

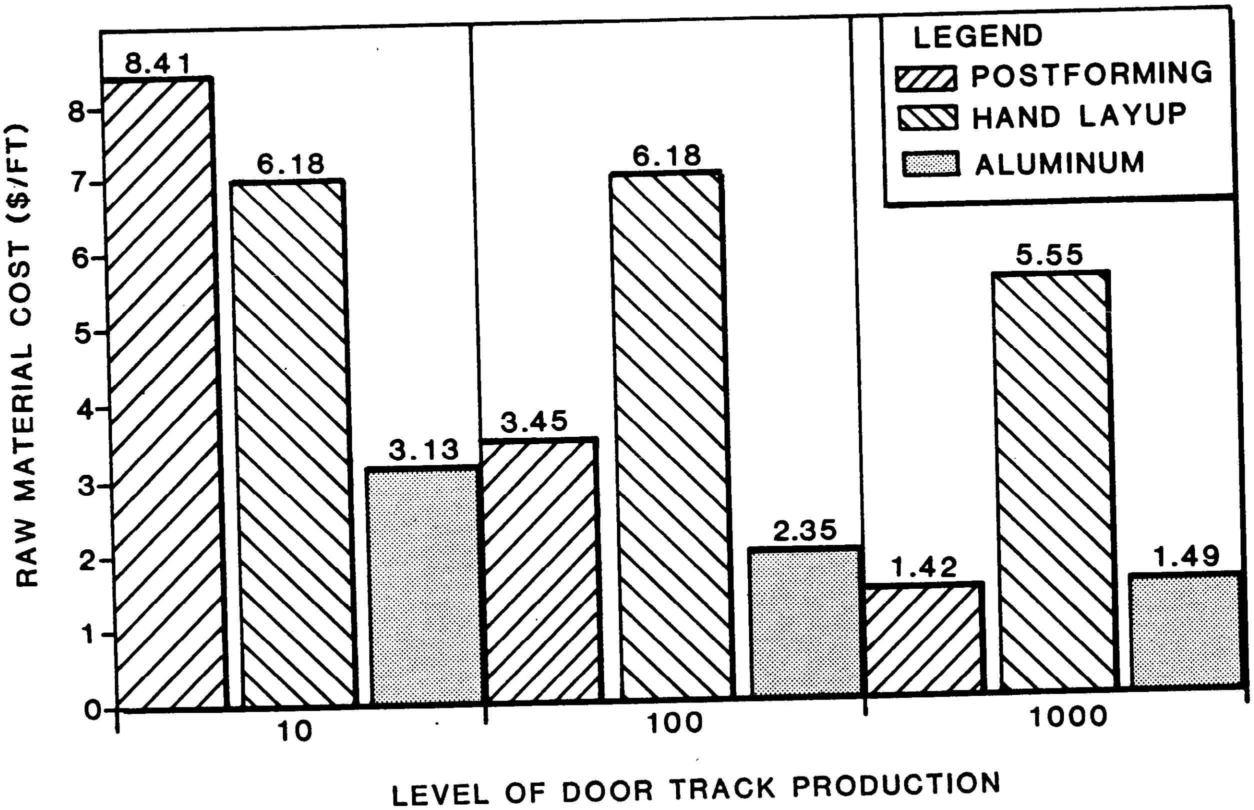


Figure 4-70. Raw material cost per foot of door track for three fabrication methods at three production levels.

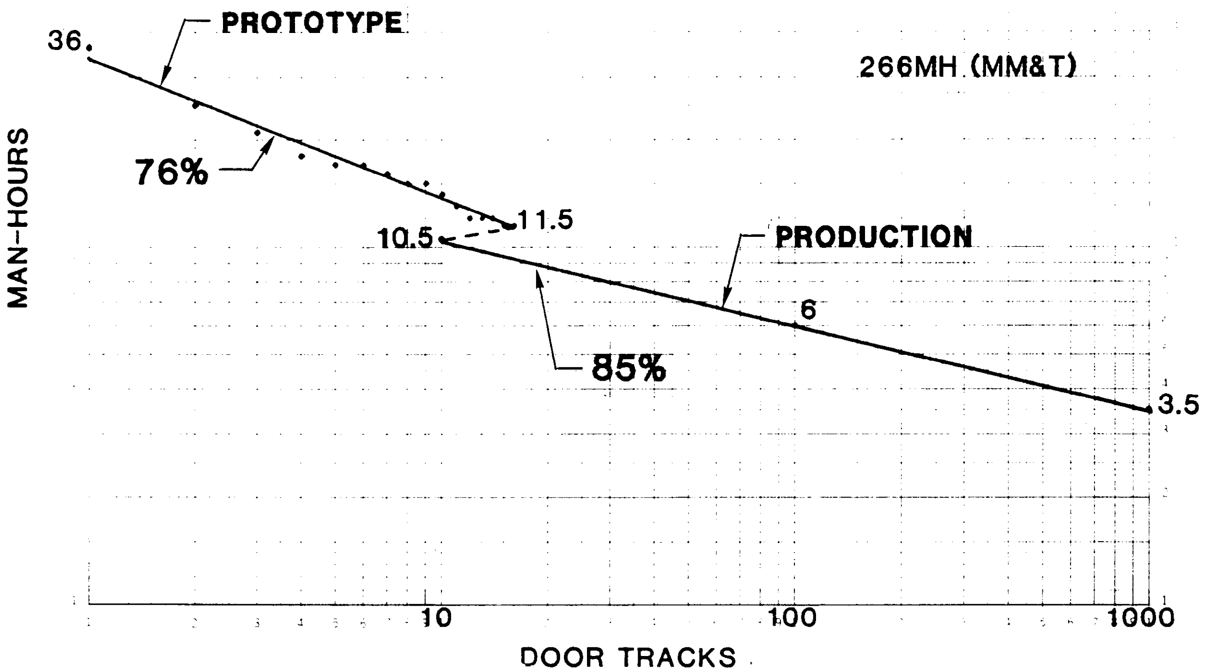


Figure 4-68. Postformed learning curves.

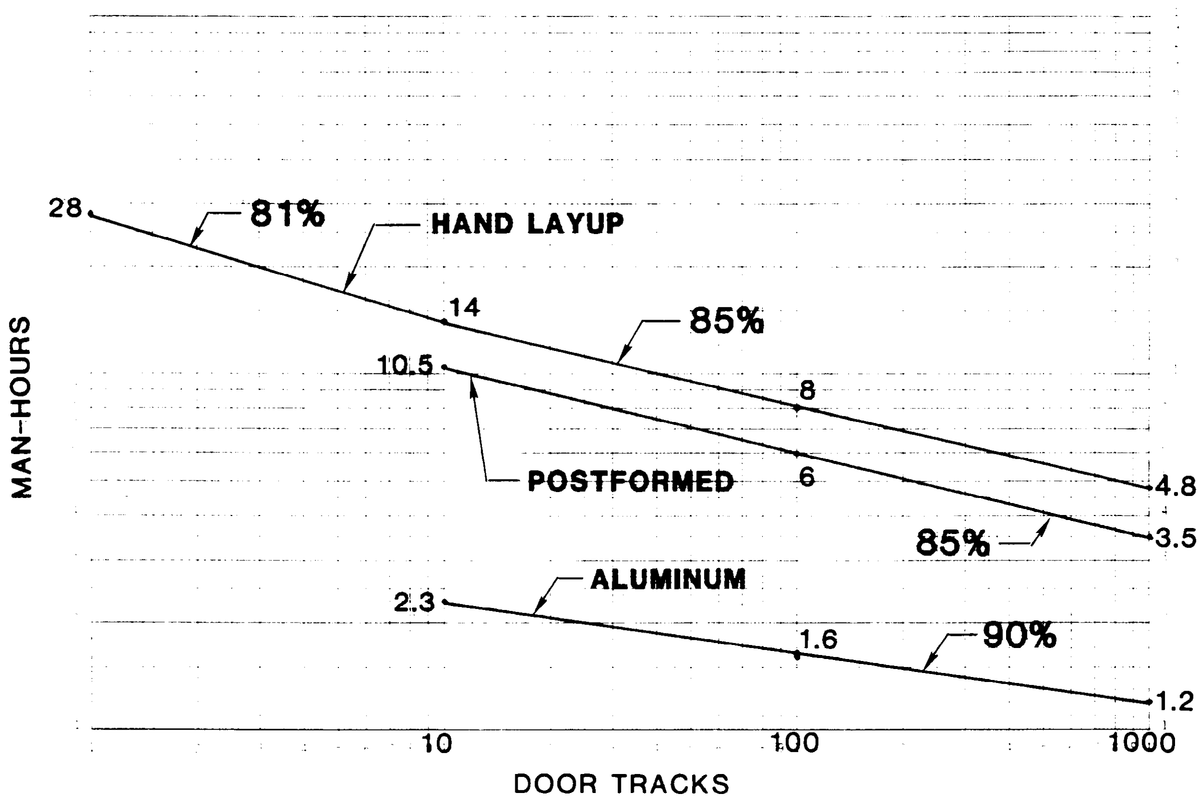


Figure 4-69. Composite and aluminum learning curves.

6. RECOMMENDATIONS

Although the program proved the technical and economical viability of postforming pultruded shapes, the following areas of exploration are recommended:

1. Define the ultimate curvature to be obtained by postforming.

2. Investigate other helicopter components.

3. Evaluate graphite/epoxy and Kevlar/epoxy to determine their processability.

4. Consider creep forming as a method to further shape the part after postforming.

5. Investigate methods of improving the handling characteristics of vinylesters due to their tremendous potential for cost reduction.

5. CONCLUSIONS

The program objective was to produce a helicopter component by pultruding a straight preform, then change the shape of that preform during cure without affecting its cross section. The program was successful because the composite door tracks met or exceeded all of the design criteria. In addition, the complex cross section of the track shows that the forming of curved or twisted parts by this method need not be limited by the cross section.

Pultrusion and postforming provide an alternative to conventional fabriction techniques where weight savings, economics, and corrosion resistance are significant.

Job No.: 81-325	Test: Pultrusion Tensile	Static X	Date: 10-23-81
No. of. Specimens: 5	Coupons	Fatigue	Fabricated By: / Tested By: / Approved:

Material: Cured Pultrusion Door Tracks | Manufacturer:

Batch: | Roll: | Uncured Resin Content: | Areal Fiber Wt.: | D.O.M.

Cure Cycle | Temp. (°F): | Time (Min.): | Pressure (psi):

Heat-up Rate (°F/Min.): | Special:

Post Cure:

Specimen Type: 0° X 90° ☐ ±45° ☐ Other ☐ | Code No. | Plies: | Special:

Loading | Tensile X Compression ☐ Shear ☐ Special ☐

Test Machine: T.O. | Test Temp.: RT | Test Humidity: RT

Static Test Rate: .05 "/Min. | Fatigue Test Frequency: | Environmental Preconditioning: 2 day water soak @ 125°F

Spec. No.	Length (in.)	Width (in.)	Thick-ness (in.)	Test Area (in.^{2})	Load (lbs.) / Mean Stress (ksi)	Ult. Strength ~~XXXX~~ psi / Osc. Stress (ksi)	Ult. Strain (%) / Osc. Strain (ksi)	Poisson Ratio / Cycles to Failure (x10^6)	Modulus (x10^6 psi)	Remarks
6		1.000	.064		5860	91563				
7		.999	.061		9460	155237				
8		.995	.063		8520	135918				
9		1.000	.054		7660	141852				
10		1.003	.063		8200	129769				
Mean:						130868				
Standard Deviation:						23907				

Tabs: .032" AL. | Tab Adhesive and Cure: EA934 - 2 hrs @ 150°F

Avg. Resin Content: | Comments: Test Method STD. #406, Method 1011

Avg. Void Content:

Avg. Ply Thickness (Cured):

APPENDIX F

LABORATORY REPORTS

Job No.: 81-325	Test: Pultrusion Flexure Coupons	Static [X]	Date: 10-23-81
No. of Specimens: 5		Fatigue [ ]	Fabricated By:
			Tested By:
			Approved:

Material: Cured Pultrusion Door Tracks			Manufacturer:	
Batch:	Roll:	Uncured Resin Content:	Areal Fiber Wt.:	D.O.M.

Cure Cycle	Temp. (°F):	Time (Min.):	Pressure (psi):
Heat-up Rate (°F/Min.):		Special:	
Post Cure:			

Specimen Type: 0° [X] 90° [ ] ±45° [ ] Other [ ]	Code No.	Plies:	Special:
Loading: Tensile [ ] Compression [X] Shear [ ] Special [ ]			

Test Machine: T.O.	Test Temp.: R.T.	Test Humidity: R.T.
Static Test Rate: .05 "/Min.	Fatigue Test Frequency:	Environmental Preconditioning: 2 day water soak @ 125°F

Spec. No.	Length (in.)	Width (in.)	Thick-ness (in.)	Test Area (in.^{2})	Load (lbs.) / Mean Stress (ksi)	Ult. Strength (~~ksi~~) psi / Osc. Stress (ksi)	Ult. Strain (%) / Osc. Strain (ksi)	Poisson Ratio / Cycles to Failure (x10^6)	Modulus (x10^6 psi)	Remarks
6		.997	.066		326	112597				
7		.999	.066		270	93068				
8		1.017	.062		264	101296				
9		1.018	058		246	107751				
10		1.020	.061		260	102755				
Mean:						103493				
Standard Deviation:						7333				

Tabs:	Tab Adhesive and Cure:
Avg. Resin Content:	Comments:
Avg. Void Content:	
Avg. Ply Thickness (Cured):	

Job No.: 81-325	Test: Pultrusion Tensile	Static X	Date: 10-23-81
No. of Specimens: 5	Coupons	Fatigue	Fabricated By:
			Tested By:
			Approved:

Material: Cured Pultrusion Door Tracks	Manufacturer:

Batch:	Roll:	Uncured Resin Content:	Areal Fiber Wt.:	D.O.M.

Cure Cycle Temp. (°F):	Time (Min.):	Pressure (psi):
Heat-up Rate (°F/Min.):	Special:	
Post Cure:		

Specimen Type: 0° X 90° ±45° Other	Code No.	Plies:	Special:
Loading: Tensile X Compression Shear Special			

Test Machine: T.O.	Test Temp.: RT	Test Humidity: RT
Static Test Rate: .05 "/Min.	Fatigue Test Frequency:	Environmental Preconditioning: 21 days @ 125°F and 95% R.H.

Spec. No.	Length (in.)	Width (in.)	Thick-ness (in.)	Test Area (in.²)	Load (lbs.) / Mean Stress (ksi)	Ult. Strength ~~ksi~~ psi / Osc. Stress (ksi)	Ult. Strain (%) / Osc. Strain (ksi)	Poisson Ratio / Cycles to Failure (x10⁶)	Modulus (x10⁶ psi)	Remarks
11		.998	.061		5800	95273				
12		.996	.063		6600	105183				
13		1.000	.063		6220	98730				
14		.994	.062		6620	107419				
15		1.000	.062		4900	79032				
Mean:						97127				
Standard Deviation:						11228				

Tabs: .032 AL.	Tab Adhesive and Cure: EA 934-150°F for 2 hours
Avg. Resin Content:	Comments: Test Method STD.#406, Method 1011
Avg. Void Content:	
Avg. Ply Thickness (Cured):	

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R.R. No. ________

TESTED BY R. Rippe

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C. Brazzel

LABORATORY REPORT

APPROVED W. C. Thoma
L. Graff

APPROVED ________

TITLE Cured Pultrusion Door Track Spec.

ITEM ________

SPEC. No. ________

VENDOR ________

Re: 81-325

Cured Resin Content, %

32.7

7872 55418

Job No.: 81-325	Test: Pultrusion Flexure Coupons	Static [X]	Date: 10-23-81
No. of Specimens: 5		Fatigue [ ]	Fabricated By:
			Tested By: Jensen
			Approved:

Material: Cured Pultrusion Door Tracks | Manufacturer:

Batch: | Roll: | Uncured Resin Content: | Areal Fiber Wt.: | D.O.M.

Cure Cycle | Temp. (°F): | Time (Min.): | Pressure (psi):

Heat-up Rate (°F/Min.): | Special:

Post Cure:

Specimen Type: 0° [X] 90° [ ] ±45° [ ] Other [ ] | Code No. | Plies: | Special:

Loading | Tensile [ ] Compression [X] Shear [ ] Special [ ]

Test Machine: T.O. | Test Temp.: R.T. | Test Humidity: R.T.

Static Test Rate: .05 "/Min. | Fatigue Test Frequency: | Environmental Preconditioning:

Spec. No.	Length (in.)	Width (in.)	Thickness (in.)	Test Area (in.^{2})	Load (lbs.) / Mean Stress (ksi)	Ult. Strength ~~XXXX~~ psi / Osc. Stress (ksi)	Ult. Strain (%) / Osc. Strain (ksi)	Poisson Ratio / Cycles to Failure (x10^6)	Modulus (x10^6 psi)	Remarks
1	1	.011	.067		274	90561				
2		.998	.067		346	115848				
3		.982	.062		264	104906				
4		.993	.068		336	109765				
5		.996	.068		338	110086				
Mean:						106233				
Standard Deviation:						9580				

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Avg. Resin Content: | Comments:

Avg. Void Content:

Avg. Ply Thickness (Cured):

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No. of Specimens: 5		Fatigue [ ]	Fabricated By:
			Tested By: Jensen
			Approved:

Material: Cured Pultrusion Door Tracks		Manufacturer:		
Batch:	Roll:	Uncured Resin Content:	Areal Fiber Wt.:	D.O.M.

Cure Cycle Temp. (°F):	Time (Min.):	Pressure (psi):
Heat-up Rate (°F/Min.):	Special:	
Post Cure:		

Specimen Type: 0° [X] 90° [ ] ±45° [ ] Other [ ]	Code No.	Plies:	Special:
Loading: Tensile [ ] Compression [X] Shear [ ] Special [ ]			

Test Machine: T.O.	Test Temp.: R.T.	Test Humidity: R.T.
Static Test Rate: .05 "/Min.	Fatigue Test Frequency:	Environmental Preconditioning: 21 days @ 125°F & 95% R.H.

Spec. No.	Length (in.)	Width (in.)	Thickness (in.)	Test Area (in.²)	Load (lbs.) / Mean Stress (ksi)	Ult. Strength ~~(ksi)~~ psi / Osc. Stress (ksi)	Ult. Strain (%) / Osc. Strain (ksi)	Poisson Ratio / Cycles to Failure (x10⁶)	Modulus (x10⁶ psi)	Remarks
11		.999	.062		222	86715				
12		.999	.056		228	109165				
13		.996	.055		218	108533				
14		.998	.063		250	94672				
15		.996	.061		266	107660				
Mean:						101349				
Standard Deviation:						10140				

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